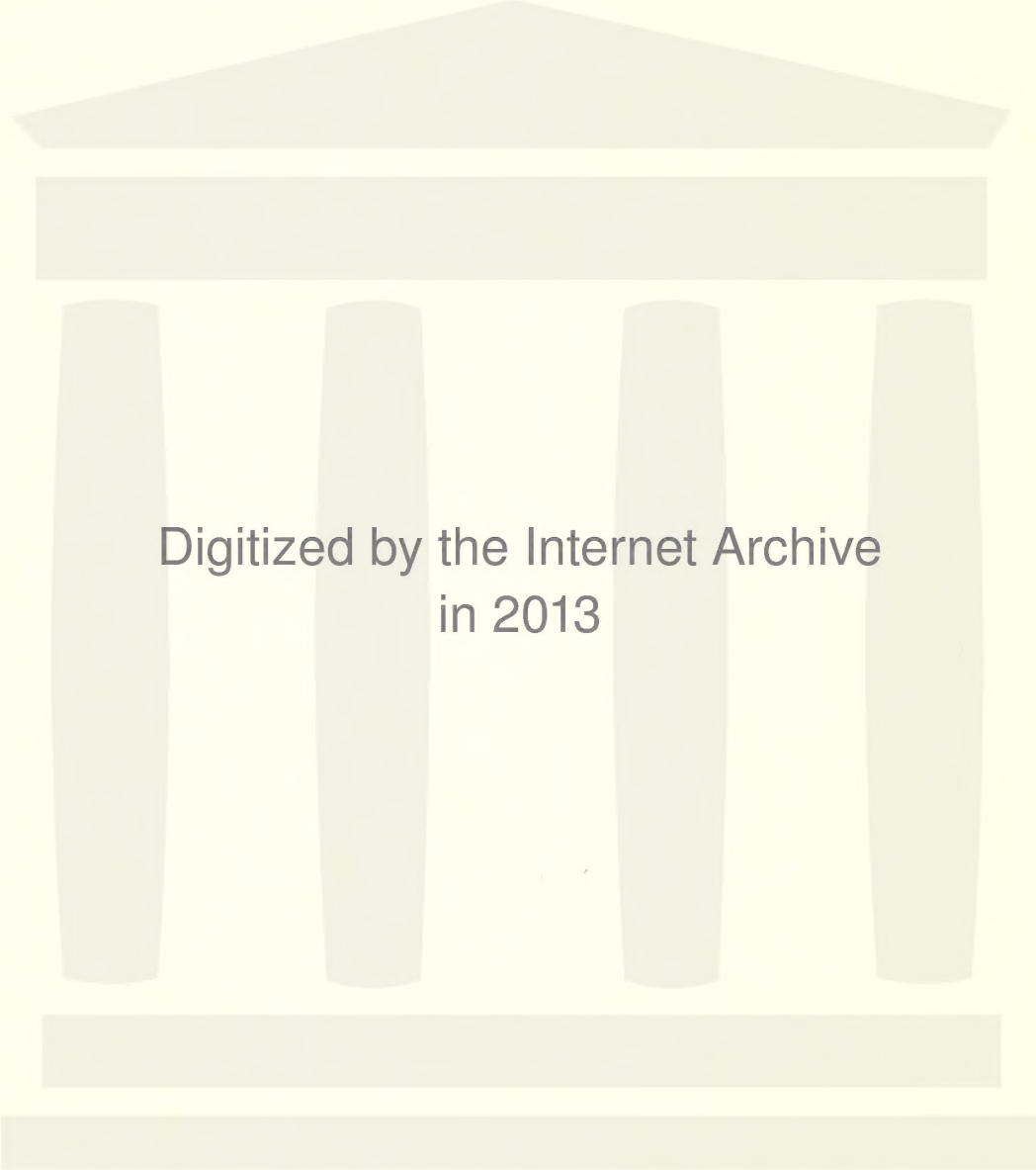




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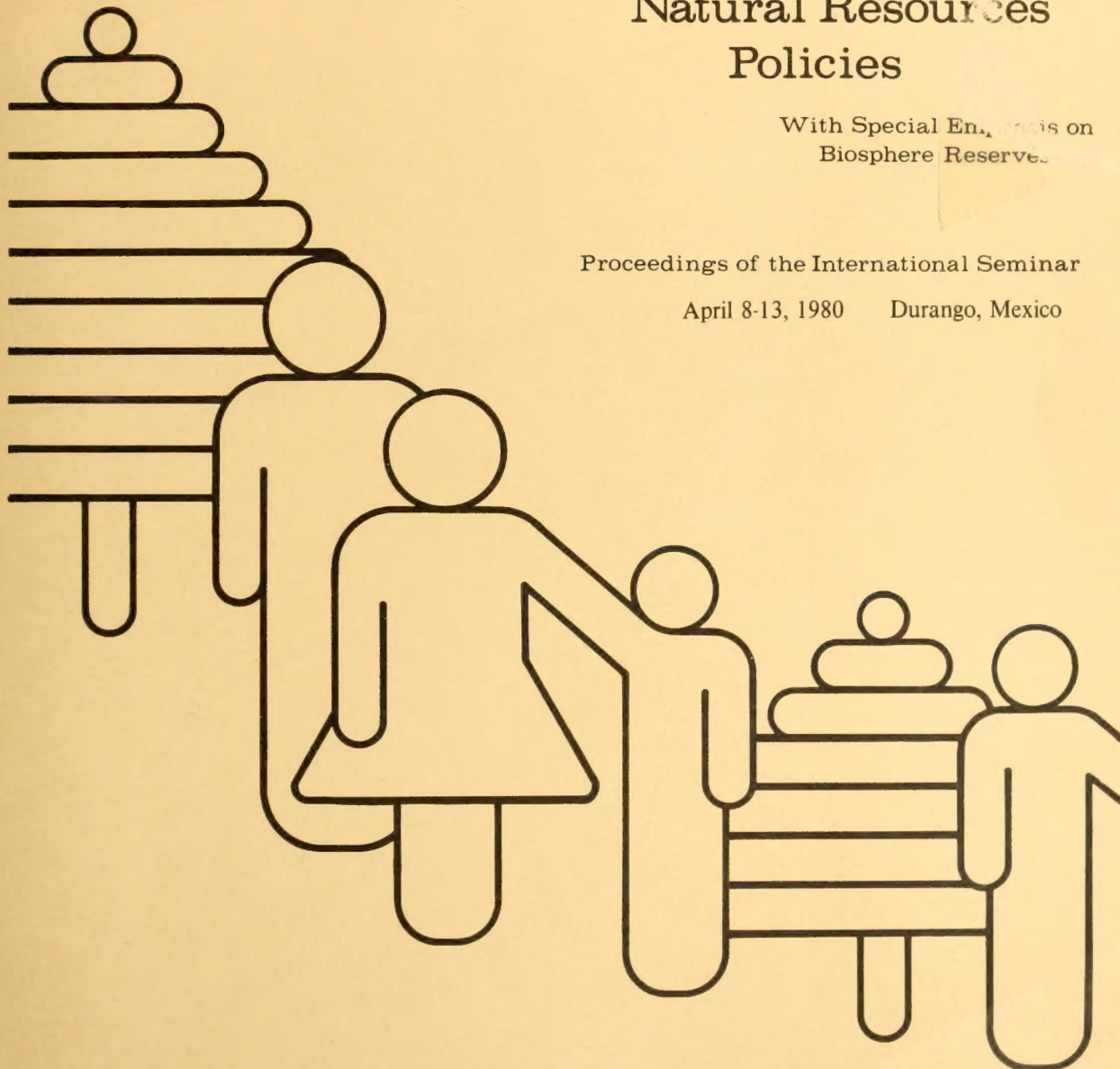


Social and Environmental Consequences of Natural Resources Policies

With Special Emphasis on
Biosphere Reserves

Proceedings of the International Seminar

April 8-13, 1980 Durango, Mexico



Foreword

The Man and the Biosphere (MAB) National Committee of the United States, in cooperation with the Government of the State of Durango, Mexico, and the Institute of Ecology, Mexico City, hosted an international seminar on the "Social and Environmental Consequences of Natural Resources Policies, with Special Emphasis on Biosphere Reserves," in Durango from April 8 to April 13, 1980. The objective of this seminar was to promote international cooperation among natural resources policy makers, scientists, and educators within the framework of the international MAB Program. In addition to the hosts mentioned above, primary support for the seminar was furnished by the Office of Science and Technology in the U.S. Agency for International Development (AID). Additional support has been provided by the School of Renewable Natural Resources at the University of Arizona, Tucson, and by the Rocky Mountain Forest and Range Experiment Station of the United States Department of Agriculture.

Through the seminar, a dialogue was initiated among upper level policy makers, scientists, and educators from both developing and developed countries on social and environmental consequences of natural resources policies. Over 65 participants from Mexico, Central America, and the United States attended the seminar. Twenty invited and volunteer papers on a variety of topics relating to natural resources policies formed a basis for formal and informal discussions among the participants. Through these discussions, a dynamic process of communication was begun which, hopefully, will be continued in future meetings.

The seminar emphasized policies that impact Biosphere Reserves, areas designated by MAB for long-term study by both natural scientists and social scientists in order to develop a basis for rational use and conservation of all that portion of the earth's crust and lower atmosphere which contains life. As part of the seminar, participants visited La Michilia and Mapimi Biosphere Reserves, both located in the State of Durango, to observe first hand the social and environmental consequences of natural resources policies imposed on these areas. Of particular interest were those parts of Mexico's Biosphere Reserves that are subject to manipulation by man. It is from these areas that people living on or adjacent to Biosphere Reserves commonly derive their livelihood.

The proceedings of this international seminar, including the 20 invited and volunteer papers and a summary of the visits to La Michilia and Mapimi Biosphere Reserves, will furnish a record of the event.

Peter F. Ffolliott
Gonzalo Halffer

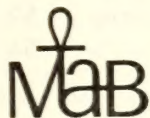
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Technical Coordinators:

Peter F. Ffolliott
University of Arizona, Tucson, Arizona

Gonzalo Halffter
Institute of Ecology, Mexico, D.F.

Rocky Mountain Forest and Range Experiment Station
Forest Service U.S. Department of Agriculture
Fort Collins, Colorado

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Social and Environmental Consequences of Natural Resources Policies¹

G.R. Stairs²

OMNIA MUTANTUR NOS ET MUTAMUR IN ILLIS -

ALL THINGS ARE CHANGING AND WE ARE CHANGING WITH THEM - a phrase that could well be our theme for this meeting and for the decades ahead. We live in a time, and look forward in our planning, to an era where wise resource policy decisions will play an increasingly important role in defining the human condition. The world, in years ahead, will be characterized largely by three forces:

1. the vital force of increasing population numbers;
2. growing per capita consumption adding a multiplier effect to the increased population numbers; and
3. new orders of mobility in terms of human resources as well as in knowledge and information systems.

In ecological terms, we are rapidly reaching the point where the ecological law of environmental resistance will prevail. That is to say, the more intense the exploitation, the more difficult to have each individual grow and reproduce.

Sociologists, economists, and political scientists talk today of a new international economic order. We have already moved from a buyer's market to a seller's market in terms of raw materials obtained from both renewable and nonrenewable natural resources. Distribution of the world's natural resources is unequal, and the reserves valued by man exist in both developed and developing nations. The political and economic power base obtainable from significant natural resources may be further enhanced by new cartels. Whether in the form of national or international associations, multinational enterprises or country-owned enterprises, these potential blocs may well dictate the major developmental boundaries for all nations.

The current world energy situation provides an example of things to come. Similar shortages, or price escalations may increasingly become common in the metals and minerals sector. We know,

¹ Paper presented at an International Seminar on SOCIAL AND ENVIRONMENTAL CONSEQUENCES OF NATURAL RESOURCES POLICIES, WITH SPECIAL EMPHASIS ON BIOSPHERE RESERVES, held in Durango, Durango, Mexico, April 8-13, 1980.

² Professor and Director, Center for Resource and Environmental Policy Research, Duke University, Durham, North Carolina, USA.

all too well, that food supplies are limited and that agricultural land and productivity bases must be increased. Wood, as a material, gains continually in world markets at a rate outstripping almost all other commodities or materials. In many parts of the world, the major source of domestic energy is wood; its availability is decreasing at an alarming rate.

Nations of the world are, at this time, meeting to conclude a 9th and final session on laws of the seas. The disparity of opinion that exists in these sessions represents an entry into the difficult questions related to multinational control of natural resources. Resources at the ocean floor are not yet well defined, nor are they technologically or economically available in many instances. Still, the speculation about their future ability to interact with land-based resources has created important and sensitive political issues. For example, the suggestion that a multinational corporation be formed that would have both policy and operational functions raises questions of financial and technological sharing. The developed world would be called upon to make concessions in this regard in favor of parity among all nations. While easily supported in an idealized sense, the proposal presents difficult questions about technological and financial support systems. The degree of complexity encountered in these negotiations raises concern about our collective abilities to resolve resource issues on an international basis where technology, ownership, and political territoriality are already deeply entrenched. Yet, as societies develop, the need for such international understanding and the development of a global-scale decision making infrastructure becomes increasingly a matter of necessity.

It is clear that social and environmental consequences of natural resource decisions at the national level may have significant impact on an international scale. Each country must begin its planning hierarchy with a global reference, and equally importantly, must be prepared to share the methodology and responsibility of decision making at international levels.

This meeting, organized to discuss the social and environmental consequences of natural resource policies, has acknowledged the interdependence among nations. It is appropriate that we dedicate a portion of our discussion to major international efforts to bring about better understanding and utilization of the world's resources. While

programs, such as "Man and the Biosphere," are an important means for developing technical and scientific exchange, they also provide a forum to discuss policy issues. The latter is particularly important, for too often we concentrate our efforts at the microscale before a good understanding of the macroscale is reached. It is all too easy for decision makers to retreat into the security of disciplinary or localized concerns and thus overlook or avoid the consequences and interaction of broader policy issues.

While our intent is focused upon sharing information at the international level, we must find specific examples at the country level. Here, we again remind ourselves that policymaking requires an understanding and appreciation of the total planning process. More specifically, it is important to view natural resources policy as a subset of national planning, and for those examples studied at this session, as a part of rural development. Designation of national parks, biosphere reserves, prime agricultural land, productive forest and grazing lands or other land uses cannot escape interaction with social and political concerns. Demographic pressures, land tenure issues, economic versus environmental concerns, and other issues must be kept in mind as we move forward to refine our scientific bases. The intent to bring senior policy makers to this forum provides an opportunity to address the question of how well national planning can accord rural development and natural resources policy designation. Is there sufficient national interest at economic, social or political levels to allow accomplishment - or are we a small group, only addressing and reinforcing our own convictions as we look inwardly at the issues? How well defined is the articulation between senior policy makers at the national level, senior policy makers in the natural resources sector, and senior scientists or policy makers at the resources management level? The discussion of these items will be at least as important to the purpose of our meeting as are issues of ecological carrying capacity, genetic reserves, or preservation of plant and animal speciation. We must concentrate a major part of our attention upon insuring that the resource policy solutions we are capable of providing at specific levels are also given attention in generic national policy schemes.

Two primary concerns face the policy decision maker when addressing questions relative to specific resource areas or issues. The first is to accord the previously discussed matrix of broad issues, the second is to bring contemporary technical and scientific competency to bear upon more specific issues. The latter topic opens discussion on a complex and growing topic. Growth in research data, an exploding knowledge and communication industry, and recently developed, advanced computational techniques provide a set of tools seemingly more than adequate to our task.

Yet, we recognize that we still have much to learn, and perhaps more importantly, many decisions to make in regard to what types of investigation or study is most important. New systematic techniques come to mind. From the well known Club of Rome Model: "Limits to Growth" to more focussed and accurate models of small ecosystems, we find examples relating quantitative and biological logic in an interpretive framework. The related opportunity to apply microeconomic evaluation to resource policy decision making has been less common, but is, nonetheless, important as an analytical concept. In most situations, there is also a dramatic need to develop time-series approaches to quantitative models so that verification of biological events is possible. To do otherwise continually delays the question of model or simulation validation, and prevents the utility of combining traditional and newly developed methodology. Additionally, there is need to develop policy that requires or encourages scale compatibility of data between studies and between sectors within study areas. Finally, there is important policy reason to consider the benefit/cost relations of resource policy decisions. But the idea of benefit/cost analysis, while not a new concept, introduces new questions for solution. How will we quantify nonmarket values? Are there real opportunities for Pareto optimalities among our policy alternatives? In welfare economics parlance, who will benefit and who will pay?

In summary, we recognize that increasing public concern for resource and environmental policy has characterized our respective nations for a period of two decades. These pressures raise questions of public control and have generally been responded to by pricing theory, by preachment (education), or by policy (regulation) authority. The dual concerns of societal betterment and just compensation are inherent policy issues, as one addresses natural resources issues. An absence of legally defined rights for land, air, or water places no private cost on environmental concerns therein related, but may carry a very heavy social cost. While the problems of resource and environmental issues may be relatable to market mechanisms, the definition of legal rights and policy must precede this action. In turn, it is necessary to base the efficiency of both upon the availability of information. And so we come full circle back to the purpose of our meeting to exchange information, to discuss policy, and to improve our individual ability to chart wise courses for the collective good of mankind.

Finally, we must consider a time table for action. I thought about defining or suggesting a time in the near future when we must begin major, increased effort devoted to wise resource policy development. A time beyond which we might not recover losses suffered, and might not regain the integrity of our ecosystems. In terms of moral obligations to human kind. ...I thought about what time to choose....and then I realized that we are already there.

Biosphere Reserves: A New Method of Nature Protection¹

Gonzalo Halffter²

INTRODUCTION

The conservation of nature and of the gene pool, or the wealth of animals and plants, has passed in this century from being an establishment set up by scientists from an intuitive and mostly ethical base for the future to a practical necessity of national and world policy. Although many of our leaders are still unaware of it, a country that destroys its ecological equilibrium and its genetic heritage closes its options for the future just the same as a country that destroys its historical heritage. In the name of temporary and controversial development schemes, and sometimes because of ignorance and lack of initiative, these countries are increasing their dependence on the industrialized countries.

Departing from the aforementioned concepts, I would like to begin my presentation with two questions, two questions which form the true base of any policy of natural resource protection in countries like ours:

1. Is it worthwhile and possible for the intertropical developing countries of today to achieve their goals with any kind of park or reserve destined to protect ecosystems, plants, and animals that does not include the people of the area as part of its structure and function?
2. In these countries, is there moral, political, and economic justification for protecting areas from exploitation when the lack of food is a reality and production must be increased?

There is no single answer for either of these two disquieting questions. The answer depends upon the position of the interlocutor relative to the problem of plant and animal conservation in relation to development, the kind of nation he wishes to construct, the socioeconomic situation of the country, and the characteristics of the local ecology.

Why are intertropical developing countries singled out in this outline? Undoubtedly, the possibilities (and problems) of natural resource conservation are totally distinct in a developing

country from those of an industrialized nation. Primarily, the high rate of population increase and the growing demand for solutions which accompany the economic development process generate strong pressures on those natural areas not yet densely inhabited or exploited. The availability of resources and qualified personnel is also not the same. In addition, the intertropical ecologic considerations are very different from those of temperate or cold-temperate countries. The richness of tropical ecosystems masks the difficulty of rationally managing them for man. Their fragility has been pointed out many times.

Because of the above and for other reasons, such as the position of the average citizen in the legal system and the public opinion on natural resource conservation, the above-referenced questions are only truly significant in countries of the intertropical zone which are trying to create their future and have the opportunity to do so.

NATURAL RESOURCE CONSERVATION POLICIES

In Mexico, our national park system demonstrates a definite influence from the United States. We try to protect beautiful or interesting areas in which the only permissible activity is tourism. National parks in Mexico are quite varied; they range from those whose extent and composition no ecologist could criticize, to parks of only a few acres in size (true public gardens).

Undoubtedly, with the exception of the most recently created parks, preliminary studies have not been made. There has not even been an ecological basis for the selection of location and extent of parks. The interests and future development of local populations has never been taken into account. In addition, the system of land ownership is confused in most cases, and although the land may not belong to the state, it is regulated by the state.

The above situation is not exclusive to Mexico, which even now has a better system of national parks than most Latin American countries.

Inadequate methods of protecting the natural resources are not exclusive to developing countries. Many highly industrialized countries are also not very efficient, and their concept of nature protection has still not adapted to the new conditions of our era.

¹ Paper presented at an International Seminar on SOCIAL AND ENVIRONMENTAL CONSEQUENCES OF NATURAL RESOURCES POLICIES, WITH SPECIAL EMPHASIS ON BIOSPHERE RESERVES, held in Durango, Durango, Mexico, April 8-13, 1980.

² Director, Institute of Ecology, Apartado Postal 18-845, México 18, D. F.

The uncomfortable truth is that, with the exception of a small group of nations, the methods of natural resource protection vary between deficient and very deficient.

The formal presentation of a reserve as such is another matter. If all parks and reserves proposed and accepted, which are officially listed by international organizations, would function today even partially, the conservation of our plant and animal richness would be assured.

In the wealthy countries with large areas without strong demographic pressures, the traditional system of national parks can be efficient; many of their parks can be, besides recreational areas, true biological preserves. In those countries when it is desired to convert the principal parks (or forest or other type of reserves) into biosphere reserves, the change is only a formality. The basic structure is already in place and working. All there is to do is adapt new, broader objectives; the original activities of the park are not excluded. One example is in the United States, where the different park systems (national, state, etc.) created to protect areas of special natural beauty for public recreation (such as tourism, camping, hunting, or fishing) are very efficient units for the conservation of plants and animals. One characteristic of the national park system in the United States, which we cannot forget, is that the laws that regulate them relate to the idiosyncrasies and needs of the country. This is what causes the average citizen, including those that live in the areas around the parks, to obey the laws and understand that they are in his own interest.

The situation in many Latin American countries is different. Demographic pressures force many people without land (and without the opportunity for any other activity than subsistence agriculture) to illegally occupy protected zones. There is no real control over hunting and, in many cases, it is difficult to see how one could be established. Forests are cut, sometimes with the complicity of lower authorities. Tourism is not organized, the most visible result of which being the discarding of trash and the deterioration of the environment.

It is easy to blame these anomalies on the inefficiency of administrative organizations. There is some truth in this supposition, and there is much room for improvement with the current system. But, we need other methods of natural resource protection if we really wish to save a significant portion of our ecosystems and the biotic material in them. The system with the most possibilities is a parallel system of Biosphere Reserves.

Why is it that national parks are not sufficient to cover all the needs for resource protection in intertropical developing countries? There are several reasons:

1. Their establishment does not include the interests, the way of life, nor the future of local populations. When the interests of the population have been taken into account, the urban population is considered more often than the rural population. Often, the only gains left to the local rural population are those from tourism.

2. They do not include the search for new forms of development (which is closely related to the first point) or new avenues for more rational exploitation of biotic resources.

3. Research is proposed (when it is) as a secondary activity.

4. The training of high level human resources is not considered.

5. In a long-range national policy, it is not the same to preserve a pretty place as it is to conserve the gene pool (the wealth of animal and plant species) as an integral part of national and world heritage.

6. Ecologic criteria are seldom essential in the selection of areas for conversion into parks. Undoubtedly, the parks do not form a system of representative areas of distinct ecosystems integrated in a global context.

For intertropical developing countries, the solution for the establishment of national parks under the conditions and priorities of today is not to do away with the park (which would be a true step backwards in natural resource conservation), nor is it to transform all of them into Biosphere Reserves. The existing parks, correctly managed, can serve very useful purposes; one of them is to provide the population with the opportunity for solace and contact with nature, something which is becoming more difficult and necessary in the large urban areas. Besides, many of the parks contain areas of exceptional beauty which undoubtedly must be protected. And, if we can improve their administrative criteria (in which there are many differences between countries), the parks can contribute to the conservation of the gene pool.

As we understand it, the solution in countries like Mexico is to establish a system of Biosphere Reserves which is parallel and complementary to that of the national parks. In certain areas, this may involve joint efforts and protected areas but in no way does it imply the abandonment of existing parks. Within the Biosphere Reserves, we include all those protected areas belonging to universities and research centers whose principal goal is the protection of the gene pool, scientific research, and teaching. The Universidad Nacional Autonoma de Mexico has two biologic research stations which are excellent examples of this type of establishment.

We have recently seen that the existence of two parallel and complementary systems of conserva

tion forms part of the new national policy of natural resource development now being developed by Brazil. Apart from the existing national parks they are creating a network of "Ecological Reserves", very similar to Biosphere Reserves, which are even managed by a different governmental agency than the national parks. There are also some protected areas controlled by universities and research centers.

In Mexico, the need for this type of parallel development is not yet understood in certain sectors. The pressure to control the Biosphere Reserves as if they were national parks is great. This appears in legal documents, which involuntarily contradict years of effort by scientists (especially in the Institute of Ecology) by committing the error of designating as an "integral reserve" all of the area selected for a reserve in Montes Azules, Chiapas. This is not simply a semantic difference. We are trying to defend the conception and development of Biosphere Reserves within the limits that we have established, without trying to replace the system of national parks and, for all of the reasons already mentioned, without allowing them to be absorbed by the national park system nor legally implanted as similar to it.

In the politics of rational use of natural resources and the creation of a natural heritage, the Biosphere Reserves (La Michilia and Mapimi) created by the Institute of Ecology with the support of the Government of the State of Durango, or created through a proposal (and background study) by the Institute itself, play a very important part. We will now make reference to some aspects of their development.

THE BIOSPHERE RESERVES OF MAPIMI AND LA MICHILIA

For the scientists, as well as the politicians that live in industrialized countries, it is difficult to attain an adequate understanding of the complex problem posed by the wise use and protection of natural resources in a developing nation like Mexico.

Within the context of natural resource protection, the basic premises and goals are universal. However, problems and pressures of every kind, especially social and economic ones, are completely different in a highly industrialized country than in a developing country. The former Governor of Durango, Dr. Hector Mayagoitia Dominguez, in his presentation at the central offices of UNESCO in June of 1979, pointed out that two aspects stand out in the web of factors and interactions present in countries like ours, between what is desired and what actually can be done, between what is planned and what is realized, two characteristics which form the common denominator of the complex problem: urgency and contradiction. In other words, the solutions must be worked out in a race against time and in a contradictory context.

In the developing countries of the intertropical zone, we must protect a rich and varied gene pool which represents more than 80 percent of the natural world heritage. Efficient conservation requires an adequate number and extent of reserves. But, it is in our countries that we have the greatest increases in a population which is still primarily rural; more people in need of more land.

Intertropical ecosystems are not easy to exploit. Their rich and diverse species composition, and the lack of technological development adequate for the exact needs of those ecosystems, make difficult the selection of efficient methods of exploitation which produce wealth and well-being while insuring the permanence of the resource. The impact of the market system on the destruction or disequilibrium of the traditional self-sufficient socioeconomic structure does not help either. On the contrary, it complicates matters. Economic pressure and proliferation of intermediaries increase the extensive and precipitate nature of the unplanned exploitation of natural resources, which keeps no reserves for the future.

It is within this panorama that we must develop, with all haste, efficient methods for protecting representative parts of our ecosystems, along with rational and planned use of our natural resources.

We have pointed out that the national park system is not adequate to protect representative sections of ecosystems. As of 1975, we have begun to search for other alternatives. The Institute of Ecology, as part of the activities of the National Council on Science and Technology (CONACYT) and with the help of the Government of the State of Durango and the Secretariat of Public Education, began to work in the Mapimi and La Michilia Reserves.

In Durango, the development of Biosphere Reserves is based on four points:

1. The willing cooperation of ranchers and peasants.
2. Research and teaching of the highest quality.
3. The combination of basic research with development programs; and
4. International cooperation.

In the aforementioned UNESCO meeting, we pointed out that the fundamental objective of the Biosphere Reserves in Durango was the protection of the gene pool and a better life for man, without opposing the interests of the human populations of the area with those of the local plants and animals.

From the beginning, we have thought that the importance of Mapimi and La Michilia should not be judged only by the protection obtained in specific

areas and certain species in serious danger of extinction, or by the good works done in the fields of population dynamics and strategies, zoology, botany, and ecological development. Mapimi and La Michilia are an experiment in a new concept, an experiment carried out at the time when our country is in search of a new policy both for the protection and the exploitation of our natural resources.

Although this approach shares many of the concerns that initiated the creation of the first large national parks, there is an important change of attitude. That is, there is concern for the people that live within the zone of influence of the Biosphere Reserves, and the search for adequate uses of the natural resources. In the long run, this is the best protection for integral reserve areas dedicated to the conservation of the gene pool.

There is another important difference. Although derived from the philosophy of the Man and the Biosphere (MAB) of UNESCO, the Biosphere Reserves in Durango are not a copy of something made on the outside. They are our own experiment, set in our reality, realized according to our possibilities.

The Government of the State of Durango has bought the areas selected as integral reserves or core areas in which the only allowed activity is scientific investigation, and the object of which is the conservation and study of the fauna and flora. However, surrounding these integral "core" areas, of their own volition, private ranches and "ejidos" (common lands) have grouped. Ranchers and ejido participants have been educated as to the objectives of the Biosphere Reserves. Through much hard work and in many local meetings, the people have been introduced to and convinced of the objectives of the Biosphere Reserves. An important part of the work of the scientists has been, and still is, the explanation of the objectives of the reserves to the rural population to incorporate the people into their work.

The areas surrounding the core areas are under production and constitute the buffer and experimental areas which protect the core. In a voluntary but efficient manner in Mapimi, the hunting of the large desert tortoise (Gopherus flavomarginatus) has been stopped. This is a great effort in a poor area where the tortoise provided a source of meat. In cooperation with the ranchers in La Michilia, we are experimenting with the joint exploitation of deer and cattle. In both Biosphere Reserves, ranchers, ejido members, and scientists work together in search of better uses of the natural resources so that, instead of destroying them, preserve them and even regenerate those parts affected by incorrect use.

Intensive work is done on new alternatives which complement and diversify the traditional uses of the land. In the periphery of La Michilia, apiculture has passed from the experimental to the

productive stage. In the same area, crops of high economic yield, such as strawberries (new to the region and requiring large amounts of physical labor) have been introduced. Agroindustries, such as the production of jam which provides better use of the local resources, have been successfully developed. Multiple use models are developed which provide rational use of game animals while optimizing the use of grazing lands and forests to increase cattle production.

Since the initiation of activities in Mapimi, a series of scientific works on population dynamics and ecologic strategies of various plant and animal species have been carried out. These works not only open a new field of investigation of Mexican ecology, but they have been a starting point of applied research of immediate utility (i.e., the increase in areas occupied by the grass Hilaria mutica, the base of the difficult desert cattle industry, or the improved conservation of water for cattle).

Undoubtedly, the development of the above works, in strict cooperation with the ranchers, has had an immense influence on their attitude toward the Biosphere Reserve. The ranchers and small farmers of the region feel that the Biosphere Reserve is their project, in which not only are scientific problems of interest to the researchers studied, but in which new solutions to their problems are also investigated. The result has been complete cooperation in the protection of the core areas, in research activities and in efforts to protect species in danger of extinction, such as the great tortoise. All of this has been achieved through cooperation and mutual effort, never by police coercion. Cooperation has come to the point where the ranchers voluntarily dedicate part of the proceeds from every head of cattle they sell to the work at Mapimi.

The vigor within these relationships which allows researchers, students, farmers, ranchers, and the authorities to establish common purposes and to work together for their completion adds to the evolution of an already priceless Mexican social structure. We are convinced that if this policy is maintained and the resources protected, more researchers will continue the efforts for rational use of the resources. The Biosphere Reserves will then be assured of permanent and effective protection of the core areas. We must not lose sight of the influence that this new focus can have on relations between man and the environment on a regional and national level.

The Biosphere Reserves of La Michilia and Mapimi do not pretend to solve all the problems of protection and management of natural resources in Mexico, or even in the State of Durango. They do offer new alternatives for their conservation and use, with a solid base in scientific investigation. It is not utopia to think that new strategies of ecological development can arise from the Reserves. On the contrary, it is an objective, as important as the conservation of natural resources.

Impacts of Policies on Specific Renewable Natural Resources: Forest Resources¹

G.R. Stairs²

Land use and natural resource policy must take care to address issues related to what society often calls marginal land. But the term "marginal land" requires definition. Society has long been willing to place high priority on prime agricultural lands and on high value urban or industrial lands. Similarly, we often give land use priority to transportation systems and communications networks. A relevant question to ask is, have the forests, grazing lands, wetlands, preserves, and other unique ecosystems been given similar attention in national resource policy setting? To the point of this paper, is marginal land a residual, excluding such areas as forest lands, or are forest lands to be derived from what the macro planner sees as marginal lands? Philosophically, it is policy relevant that a well-defined categorical identification of forest land be obtained; practically, it is absolutely important if we are to obtain appropriate societal valuation of these valuable lands.

At the global level, we have about 13 billion hectares of land: 4 billion are forests, 4 billion are grazing areas, 1.5 billion are agricultural, and the remainder (3.5 billion) are tundra, snow, ice, desert, or rocky areas. The world pressure to expand food production calls for expansion of the agricultural sector to about 3.2 billion hectares. Such a policy requires land use transfer from forest and grazing uses to intensive agriculture. A major proportion (1 billion hectares) will probably be obtained from the world's tropical forest regions. Alternatively, one could suggest that a policy of utilizing tree food crops could become a "middle ground" between traditional forest management and intensive agricultural cultivation.

In any event, it is clear that forest land will continue to be under pressure from new societal needs and land use policies, as well as from additional forest uses. Historically, forest lands have primarily been exploited for wood as an energy source; cleared for agriculture, suffered

depletion due to grazing impacts on vegetation and soil, or utilized for wood as a material. The amenity values of recreation and the value of watersheds and wildlife habitat have often been overlooked in serious planning or management. As a result of historic and current exploitation, the world's forest lands are badly managed and are being reduced in size at an alarming rate. At the current rate of depletion, the forest areas in developing countries (1,200 million hectares of mature forest) will be consumed in about 60 to 90 years. The current depletion rate, about 15 million hectares per year, will be further increased through agricultural expansion and increased consumption by the 200 million people who live within or near these forests.

Despite the obvious importance of the forest as a renewable resource for national economic and social stability, there has been little effective policy to reverse current trends. In the developing nations during the past two decades, investment by governments in the entire agricultural sector, (including forestry and grazing) has averaged only 12 percent of the total national development program, despite the fact that the gross national product contribution from this sector has averaged over 30 percent in these countries. The portion of investment by the agricultural sector in forest land restoration and management has been only a fraction of that devoted to food production and cash crops grown under intensive cultivation. A further paradox relative to past policy decisions may be seen in the rapid price escalation of wood as a material moving in international trade. In developing countries, export values for wood have risen from \$1,500 million in 1970 to \$3,000 million in 1975. Annual world production of forest products is over \$115,000 million, while that portion moving in international trade is over \$30,000 million. The trend seems well established, and it is highly likely that there will be even greater demand for wood as a material in the next decade. Wood products have steadily remained one of the most rapidly rising (in terms of price) trade items among all commodities.

¹Paper presented at an International Seminar SOCIAL AND ENVIRONMENTAL CONSEQUENCES OF NATURAL SOURCES POLICIES, WITH SPECIAL EMPHASIS ON BIO-HERE RESERVES, held in Durango, Durango, Mexico, July 8-13, 1980.

²Professor and Director, Center for Resource and Environmental Policy Research, Duke University, Durham, North Carolina, USA 27706.

Thus, we may view the forest land sector as threatened by growth, both in traditional exploitation areas and by increased efforts to expand agricultural and other land uses. These issues require more policy attention than they have received in most countries. The micro- and macro-economic consequences of land use policy should be quantified as part of overall natural resources policy analysis. Too often we attempt to introduce forest

sector recommendations into national resources planning without an appropriate look at the welfare economics inherent in these situations. As alternative uses for land become more active, it is necessary to quantitatively define both market and nonmarket values and to provide qualitative, professional, moral, or ethical judgements. In particular, the forest sector must be included in broader rural development policy making as a part of comprehensive land use and natural resources planning.

Turning to policy issues within the forestry sector *per se*, we may usefully segregate our concerns into environmental or ecological issues; and commercial aspects, with consideration for both domestic and foreign trade. Both major sectors may be further analyzed in relation to subsistence and local needs, as well as in reference to future national resources planning. It is important to develop a policy that will bring the forest resource sector beyond subsistence levels and into prominence as a major renewable natural resource.

The success of political and societal decisions in the future will rest heavily upon the natural resources base. It would seem increasingly obvious that political and policy deficiencies of the past cannot continue in the decade of the 80's. An African leader, Zaire President Mobutu Sese Seko spoke recently about the importance of food: "In the coming years the wealth of a country will no longer be evaluated in terms of diamonds, nor of gold, nor of copper--but rather the capacity of each government to know how to feed its people." His statements could as easily, and perhaps more precisely be broadened to include the renewable natural resources base and our ability to provide quality-of-life materials such as those values available from our forest lands.

Policy dimensions related to environmental concerns must first address resource conservation and utilization issues. Local demands for fuelwood, grazing, and wood as a material cannot be sustained in perpetuity under conditions that currently prevail in most areas. Policy alternatives may be varied relative to the mix of goods and services to be obtained from a given land unit, but there cannot be tolerance for terms that would allow either short or long-term site degradation. Devastating past practices must be corrected through major intervention programs. The societal values to be placed upon the forest reserves increases steadily and a policy for narrowing the gap between the resource value and the national input to forest restoration and management must be closed. While policies should be developed to allow decentralized, local inputs, it is unlikely that local areas will be able to correct past practices without central government support.

Defining environmental or ecological policy in terms of recreational use, preservation, conservation, or other amenity value is relatively easy in the qualitative sense, less so in quantitative or econometric terms. Nevertheless, it is vitally

important to adopt natural resources policies that require economic analysis for both market and non-market forest values. Soil erosion problems, lowered water yields or quality, and the overwhelming impact of encroachment and shifting agriculture are items that must be assigned real value in terms of social and monetary costs. In addition, the cost of regaining or delaying corrective action must be defined. While estimates of input and output values should be derived from willingness to pay evaluations, we know these benefits and costs typically may extend over hundreds of years and thus economic discount rates, as well as social valuation, must be used. Selecting a discount rate and determining willingness to pay are topics appropriate to advanced economic study. Sufficient to our purpose in this discussion is the call for sound economic analysis as a prelude to final policy decision making.

I have suggested herein that a hierarchy of policy needs must first recognize the need for conservation and restoration of the forest resource. A second stage will be to select a management policy that will provide the mix of goods and services desired and to allow for deviation only under carefully monitored conditions (fig. 1). A third state relates to the need for domestic consumption and for local use or export and industrial production. Provision for local use will usually take priority, in most regions from lands nearest settlements. Policy selection may favor subsidized use of forests at the local level as a more effective solution than alternative economic or development programs. The use of wood for energy in direct combustion, alcohol production, or charcoal provide examples.

The potential for wood as a material in trade increases daily. National needs for low-cost housing suggest the potential for articulated systems integrated from forest to urban housing schemes. The pulp and paper industry will continue to rank well in progressive economies. Tree food crops may become locally important in many regions. As these industrial programs develop, policy issues relating management costs for restoration and productive use of forest land must also account for the social and economic values therein. There is opportunity to develop labor-intensive programs and to stimulate rural development. Secondary manufacturing at appropriate scale in wood products may help to stabilize local economies and seasonal labor force. The opportunity for training workers can be taken with a view not only to forest operations but also to related construction trades. Finally, the externalities of forest development must receive careful policy attention. Development of a commercial sector may have impact on other welfare or profit systems in the nation. Within the forest sector, trade-offs exist between various uses such as timber production, watersheds, and grazing. These induced effects within the commercial system must become part of a benefit-cost policy analysis.

Thus far in this presentation, discussion has focused on policy related to restoration, conservation, and then utilization of forest resources.



Figure 1.--An example of a Southwestern forest managed for a mix of goods and services, including timber harvesting, grazing, and wildlife habitat (U.S. Photo Service photo).

There remains a need to further define policy for forest reserves. These areas are maintained in association with managed lands but are protected against the loss of their natural character. Even here, policy alternatives may range from completely protected natural systems to partial utilization, either in space or time. For example, it is possible to think of "recycled" wilderness even though this goes against our normal definition of a reserve or natural area. Reclaiming lands for preserves falls in this category, as would a policy for maintaining reserves on a cyclic basis over long periods of time. For example, reserves may be moved into and out of recreational use, light commercial harvest, watershed protection, or grazing dependent upon carefully defined management practice. In this method, we would be opting for a much less rigid definition of reserves or preserves, and would be defining a graduated series of land classification rather than a system with abrupt discontinuities.

The policy alternative for forest reserve establishment represents the most critical of our decision set. While policies must recognize a continuum of land use classification, there must be reserved a special category for these lands. It is here that we find it most difficult to regain the natural status desired and to maintain it against encroachment. It is also on the reserve lands that a great deal of our future forest ecosystem research will be conducted. Maintaining reserves of natural diversity, study of competition and site requirements, and related biological

or physical relations have meaning beyond the naturalists' interest. As more intensive land use practices become increasingly commonplace, it is vital that representative natural areas be maintained as insurance against man's mistakes. The Man and the Biosphere (MAB) program provides an operating research policy to reinforce this concept and it is vital to international cooperation and coordination. In particular, the MAB program allows exchange of scientific and technical information at sessions such as this one where policy-level considerations can be discussed.

In closing, I suggest to you that the concepts of this session should be seen as an open door to future interaction among our countries and institutions. Yet, we also need to be cognizant of other bilateral and multilateral efforts and to also relate our work to these existing organizations. It is a common practice to start new committees or organizations at each major meeting, and that may not always be the most efficient means for obtaining coordination. Nevertheless, I feel this meeting, with its focus on policy issues, provides a theme that is worthy of continuing. I hope and trust that we can continue to build upon this start toward a future of better understanding and information exchange for forest and related natural resource policy issues.

The Impact of Natural Resource Management Policies on Forest Resources¹

Jose Trueba Davalos²

INTRODUCTION

The social and environmental consequences of natural resource management policies with special emphasis on forest resources, which is the focus of this seminar, have been, frankly, noxious. This is because of the impact of management policies on the forest resources. However, to proceed in an orderly manner, it is indispensable to set forth a frame of reference with which to begin the analysis of the problem.

A FRAME OF REFERENCE RELATIVE TO THE PROBLEM OF FORESTRY IN MEXICO

The forested surface of Mexico is composed of those areas covered by trees, chaparral, brush, grasses and forbs. It covers a total of 137.2 million hectares, or about 69.8 percent of the country. This vegetative cover is natural and develops in those zones whose topographic constitution have permitted its spontaneous development.

The Forest Inventory Classification divides the forested area into wooded areas and other forested areas. The wooded areas extend over 44.2 million hectares (22.5 percent of the national area); the "other" forested areas contain 93 million hectares (47.3 percent).

Wooded areas are those forested areas in which well-defined communities of trees predominate, and which have a certain density level; these areas are divided into forests and jungles.

The forested area currently occupies 29.2 million hectares (14.9 percent). Forested areas are divided into coniferous-hardwood forests, which extend over 20.6 million hectares (10.5 percent) and hardwood forests, which cover 8.6 million hectares (4.4 percent).

Jungles comprise 15 million hectares, or 7.6 percent of the national area. They are classified

¹Paper presented at an International Seminar on SOCIAL AND ENVIRONMENTAL CONSEQUENCES OF NATURAL RESOURCES POLICIES, WITH SPECIAL EMPHASIS ON BIOSPHERE RESERVES, held in Durango, Durango, Mexico, April 8-13, 1980.

²Subsecretary of Forestry and Fauna and Director of Reforestation and Management of Forested Soils, Netzahualcoyotl 109, Mexico 1, D.F.

into high jungles (2.4 million hectares or 1.2 percent) and middle jungles (12.6 million hectares or 6.4 percent).

There are two other forest classifications: Disturbed areas (16.4 million hectares, or 8.3 percent of the country) and aquatic vegetation (1.1 million hectares or 0.6 percent).

Of the 137.2 million hectares which constitute the forested area of the country, only 44.2 million (22.5 percent) are considered wooded areas and are therefore, productive lumber areas for different uses.

In seven states of the Republic, 67 percent of the 29.2 million hectares of temperate or cold forests are concentrated. They are Chihuahua, Durango, Jalisco, Michoacan, Guerrero, Oaxaca, and Chiapas. In another six states (Veracruz, Campeche, Chiapas, Yucatan, Oaxaca, and Quintana Roo), 80 percent of the 15 million hectares of hot-humid forests are found.

The estimated reserves of economically usable log timber and their productive potential for 1975 are summarized in Table 1.

Table 1. Economically Usable Forest Reserves in 1975³.

	Area (Ha) (Millions)	Existing ³ Volume m ³ (Millions)	Annual Potential m ³ (Millions)
Conifers	14.7	1,250	21.6
Leafy trees	14.8	550	7.6
Total	29.5	1,800	29.2

Although these data are for 1975, they can be considered generally valid through 1980.

The participation of the forest sector in the Gross National Product is very low, and in the last 18 years has shown less dynamism than has been shown in almost all the other sectors of the national economy (Table 2).

It is estimated that by 1977, approximately two million people participated directly as owners

³Castillo Fragoso, Ruben "El Presupuesto de la Federacion en el Sector Forestal." In The Periodical "Mexico y sus Bosques," Volume XVII. April, May, June of 1978. No. 2, Page 4.

Table 2. Participation of the Forestry Sector in the Gross National Product between 1960 and 1978.

Year	GNP	% Increase	Forest GNP	% Increase	Participation In the Total GNP %
1960	150.5	-	0.882	-	0.6
1965	212.3	7.2	0.935	1.2	0.4
1970	296.6	6.8	1.149	4.4	0.4
1975	340.3	5.8	1.337	3.2	0.3
1978	432.3	3.5	1.477	3.4	0.4

of the forest, and by the year 2,000, this population will increase to 3.5 million. However, the population now living in wooded zones, approaching ten million inhabitants, could increase to 16 million in the year 2,000.⁵

The forested area is distributed into approximately 500 landed common areas or "ejidos," 100 communities, and 180,000 private parcels. These data, according to the information source, are approximate, due to the lack of accurate information on the subject. The area under organized production is reduced to that represented by 600 ejidos, 12 communities, and 1,300 private parcels. The rest is considered as potential area but, at present, unorganized or under marginal forest production.

Of the 7.6 million cubic meters of log timber produced in 1978, private companies produced 4.7 million cubic meters, state-owned companies produced 0.9 million cubic meters, decentralized organizations produced 0.8 million cubic meters, the ejidos produced 1.2 million, and the unorganized sector, of which a productive potential of 6 million cubic meters annually is considered, produced 0. It is estimated that the entire annual productive potential is 22 million cubic meters, instead of 7.6 million cubic meters now being produced. The National Forestry Plan has established the goal of 11.2 million cubic meters by 1982.

The organized and productive forestry sector is represented by 600 ejidos and 12 communities, as has already been said, of which 47 percent are yielding a return, and by 1,300 private parcels, of which 85 percent are yielding a return. There are 780 productive organizations.

As can be seen, private companies generated 73 percent of the forest production in 1976, and state companies (federal and state) produced 10 percent (Table 3). The ejidos produced only 17 percent.

⁴Average annual rate in the period. Source: Bank of Mexico.

⁵The data presented on this page are from the Annual Report of "La Direccion General para el Desarrollo Forestal 1978" S.A.R.H. Subsecretaria Forestal y de la Fauna. Mexico 1978 page 1-35.

Although the data compared between 1970 and 1976 indicate a reductive tendency in the private companies, which dropped in production from 81 percent to 73 percent of the national total, production is still practically three times the state and ejido production, which together is only 27 percent.

But given the nature of the companies, instead of grouping the state companies with the ejido companies, the state companies should be grouped with the private companies which, together, manage 83 percent of the forestry production compared to 17 percent managed by the ejidos.

Within some of the ejidos, the administration (or, in other words, the participation of the ejido members) is organized exactly the same as in the capitalist companies. A very small "cutting license" is paid for the extraction of wood; later, the small profits or losses are divided. This is interpreted by a critical ejido member as resulting from a bureaucratized, unproductive, and even corrupt administration that hides and manipulates information and administrative participation to filch the profits from the members.

Whether or not these critical observations in relation to the ejido-run companies are true, in many cases the administration is run by a group of technical bureaucrats and the participation of the ejido is reduced, in the best cases, to a small cohort of leaders whose honesty is also frequently questioned by the ejido base.

A COMPREHENSIVE LOOK

What inferences can be drawn from the summary of data?

1. The forested surface of Mexico is immense, almost 70 percent of the entire national area.
2. Its contribution to the Gross National Product is negligible, less than 1 percent.
3. The data is explained, in part, because the wooded forested area only represents 22.5 percent of the national area, and the conifers and hardwoods, which are the most productive economically speaking, only comprise 14.9 percent. Although in this light, matters appear to change, it is impossible not to reflect upon the modest economic productivity of the wooded zones and the insignificant productivity of the nonwooded forested area, which represents 47.3 percent of the national area and whose components, altogether, cover 93 million hectares.
4. The consequence of this low productivity is that Mexico has to apportion 5 billion pesos annually to buy forest products, especially celluloides, from other countries.

However, the problem is not that serious. In fact, with a new forest production plan, we hope to gain self-sufficiency by producing a little more than 11 million cubic meters of log wood by 1982.

Table 3. Forms of Organization for Production or Industrialization (1970-1976).

	NUMBER		NATIONAL PRODUCTION		PERCENT ⁶	
	1970	1976	1970%	1976%	1970	1976
Private companies with ordinary licenses	more than 200	more than 150	67	67	40	40
Private companies with industrial units of forest exploitation	10	6	19	86	22	62
State companies with forest exploitation units	3	3	5	91	11	73
Decentralized federal organizations	1	3	-	--	5	78
Decentralized state organizations	2	5	2	93	5	83
Ejido companies	±30	±130	7	100	17	100

A true statement of the problem is that the important costs are ecological and social. However, it is difficult for a society stuck in the one-dimensionality of economics to understand that ecological and social costs exist.

Lets try from another perspective to understand the forestry problems of Mexico. Natural resources have, historically, constituted a kind of natural infrastructure by which the small settlements of old satisfied their needs. These primitive settlements lived in symbiosis with their ecosystems, and generally, attributed to them the birth of the human race, and rendered unto them some kind of homage. The study of primitive cultures now living in little-known regions has verified this historical hypothesis.

During many thousands of years, man survived by hunting and gathering, which were frequently practiced in forest or jungle ecosystems. In this early period of history, man practically formed part of the ecosystem, to which he adapted without being able to significantly alter it. The objectives of this kind of society were quite simple, very related to their own subsistence, and probably with much available free time.

However, as economic, social, political, and cultural changes took place, and as society began a process of becoming more complex, the attitude of man toward nature began to change. It has been almost a historical constant for a long time, and still is in most of the world, that ecosystems were destroyed as the great civilizations and

important cities of classic antiquity developed. There are historical testimonies of many forests destroyed near large metropolises.

"The deterioration of the environment," affirms David Dickson, "has always been related to social and economic development." Long before the birth of Christ, enormous forests of the Near East were reduced to areas without vegetation due to agricultural activities and to their loss of protection from the wind. This, along with centuries of intensive grazing, turned said forests into arid deserts.⁷

In his celebrated literary work, Plato also mentions this process in reference to Greece: "The soil continually sloughed off the mountains...slid without stopping until disappearing into the sea... what now remains, in comparison with what was once there, is like the skeleton of a sick man; all of the soft and fertile land has been consumed, only the naked frame of the earth remains...what now are mountains were once high hills covered with soil; the rocky plains of today were replete with rich soils, and the mountains were populated with dense forests, of which some traces still remain. There are mountains in Atica that today can support no more than bees, but which, not long ago, were covered with beautiful trees, now appropriated for the roofs of the major buildings, there are still some roofs made from their wood... The country produced unlimited grass for cattle.

"The annual rains were not lost as they are now by running to the sea over the naked ground. Instead

⁶Data approximate. Source: Office Report of the Direccion para el Desarrollo Forestal 1978.

⁷Dickson, David. "Tecnologia Alternativa" Editorial--Blume Madrid 1978. Page 3.

n all their abundance, they were received into the rest of the country where they were kept in her impermeable clays until she evacuated the excess from the heights to the valleys in the form of deep rivers and springs, abundant over large areas. The Temples still standing in places where water once flowed demonstrate the truth of my hypothesis."

This classic text could be applied to many countries and regions, and in several ways is reproduced in the studies of this problem in Mexico.

"Today," affirmed Hans Lenz in 1948, referring to the forestry problems of Mexico, "the pitiless axe, driven by the poverty of the Indian, by the thirst for profit in some people or the ignorance of others, and forest fires devastate thousands of hectares, converting areas of rich vegetation into tracts of naked land, impoverished by erosion and useless for cultivation...where the hand of man has sacrificed majestic trees, useless weeds and sickly bushes are born; if the hillsides are affected, the springs dry up, the forest soil disappears through erosion...entire regions that were once privileged by their vitality, become deserts."⁸

In the same vein, the Forest Engineer Rigoberto Vasquez writes: "Agriculture, cattle, and forests constitute the foundation of survival of the people, and are based on productive soils."

"The soil as medium and water as the vehicle form the unit of production, but the determining factor in the functional equilibrium of them is integrated by a third element, which is the forest vegetation. The three form an indisputable triad which contains the key to human life."

"In order of dependence, agriculture and cattle are subject to forest vegetation, because the soil, hydrologic and climatic regimes, along with the condition of the soils depend upon the condition in which the vegetation in the high regions and watersheds of the mountains is in. It is necessary to understand that runoff waters and erosion control do not end with the construction of irrigation dams, nor with the cultivation of the flatlands, but on the slopes of the mountains, where the protective action of the forests, and only the forests, can combat the destructive force of the aquifers, erosive winds and floods."⁹

This perspective, which considers not the wood and not even the forest, but the ecosystem, as the true natural resource, constitutes the correct dimension in which the true value of the forest resource must be appreciated as an essential component of its own forest ecosystem. Not only that,

⁸ Lenz, Hans and Wagner, Helmuth. "El Bosque y la Conservacion del Suelo" Editorial Cultura. Mexico 1948. pp. 14-15.

⁹ Vasquez de la Parra, Rigoberto, "Obras de Restauracion al valle de Mexico y de Proteccion a la Ciudad."

but the forest ecosystem must be considered an element of a wider ecology. Even the so-called artificial ecosystems, as certain compact and homogenous zones of agricultural activity, and even the cities themselves (urban ecosystems, as they have been called), depend upon the forests.

It is in this ecological perspective that the forest acquired its relevance. The economic input of forest products (less than 1 percent of the Gross National Product of Mexico, although still with some importance) does not constitute the parameter by which the value of the forests should be measured, not even in other countries where their input into the GNP may be more considerable.

The significance of the forest achieves its true dimension when visualized as protector of the soil, conservator of water, reproducer of organic material, oxygenator of the soil, processor of solar energy, not to mention more of its biologic functions.

Wood constitutes no more than one of the secondary products of the forest. This does not mean that wood should not be exploited, or that its productive potential should not be increased, but that it should be considered in its true perspective as a subproduct, in a context in which the true value of the forest is its quality of conditioner of life and fertility.

This is how the forest was perceived, with a deeper ecologic conscience, by the primitive peoples whose lives depended upon the functioning of the ecosystem, which has been verified through studies of societies which still maintain certain socio-cultural traits similar to those of primitive societies.

The difference between these two concepts--the forest as an ecosystem or as a resource--is intimately related to the two kinds of societies, the primitive and the modern. The latter is organized through a state with a large population subdivided into many sectors which occupy diverse economic activities, many of which live and work in the city and are very disassociated from the forests and ecosystems, of which they are frequently ignorant or are poorly conscious of the vital function played by them in the whole of society.

This modern society is organized under the euphemism that "business is business," for which wood has an exclusively economic meaning in monetary terms. This society, which is oriented toward producing massively for the demand of a gigantic market, voraciously consumes all kinds of raw materials and is structured under the name of gigantic international companies which assume the prerogative of defining the decision-making hierarchy of values. Modern society establishes what has become the prototype of the role played by these companies in the national context, the maxim that "what is good for General Motors is good for the United States." These companies are, because of the set of values they establish, a utilitarian ideological reductionism, very far from being capable of correctly

appreciating the ecological costs of the destruction of a forest or the social costs of appropriation of a raw material. Survival depends more on maintenance than on exploitation of the great community (ecosystem) of the which they use only part. They understand that their objectives are limited by the cyclic nature of biologic structure and the necessity of maintaining it.

It is worth pointing out that the Maring (name for the members of one of these primitive contemporary tribes) and other inhabitants of New Guinea conceive the world as a collection of cyclic processes. Not only are there orchards and forests (in their opinion simply different phases of the same cycle), there are also growth and decomposition of the oldest plants. The Maring call the spirits that care for the fertility of the orchards, pigs, and man, Rauua Tukup, which means "spirits of decomposition." These spirits are responsible not only for fertility, but also for death.

I suggest that ecological cycles, evident to the Maring, are hidden to the people of an industrial society because of the mere dimensions and complexity of such a society. For this reason, ecological considerations influence less and less in the objectives of society, for the simple reason that the ecological conscience decreases more and more, even where there is a certain understanding of ecological processes. (The economic interests of the human group interested in the direct benefits derived from the exploitation or use of the resource takes its place, to the detriment of the general or public interest of society.)

What is the value of photosynthesis in monetary terms? Of the development of organic material? Of the decomposition of organic material in the soil? Of a spring 30 kilometers from the forest? Or the price paid by the fact that 65 percent of the Mexican rural youth are being expelled from the rural environment to go work in the city?

In a company with a capitalist mentality (be it North American or Mexican, automobile producing or forest oriented), short-term gains are the only concern; ecological and social costs are simply ignored or transferred or, in the best of cases, evaluated with the same monetaristic logic.

These councils of stockholders from the world decision-making centers, from the capitals of the Third World countries, or from the Directive Council of some forest company under the pressure of the large institutions mentioned above, proceed as if there were no other criteria for decision making than those of their own immediate and monetary logic.

Whole countries are converted into sugar cane fields or coconut groves. Within the most unstable ecological systems on earth are found fields dedicated to the monoculture of "miracle strains" which can only mature if given huge quantities of

fertilizers, herbicides, or insecticides which frequently must be imported over long and unreliable routes.

"It seems as though species diversity is also suffering as a result of commercial exploitation. Logging or wood-related industries tend to favor plantations of a single species of the same age group, which is the closest that silviculture can come to agriculture, with all of its problems and defects."¹⁰

This critical analysis does not pretend to advocate the suspension of the economic use of the forest, nor a return to the system of primitive societies. This analysis advocates that economic simplism be abandoned and ecologic and social criteria be established, similar, for example, to those proposed in the Eighth World Forestry Conference held in Jakarta, Indonesia, celebrated in late 1978, which sets forth in its Final Declaration a series of conclusions and recommendations which, although proposed on a world level, are essentially valid for Mexico.

There now exists all over the world a tendency to reduce forested areas, along with the growth of the population that lives in the forest and of the forest. This fact is alarming if you consider that in every region of the globe there is a close relationship between the existence of forest ecosystems and the availability of water and, in particular, the fertility and capacity of the earth to produce food for a deprived human population which annually increases by seventy million people.¹¹

The forests of the world still cover a large area; their biomass is by far the greatest of all types of vegetation. However, urgent and efficient methods are needed to contain their destruction, which is pressured by millions of people that depend upon forest resources in order to survive and to better their living conditions, and who frequently advocate the change in use of the soil and the transformation of forested areas into agricultural or cattle-producing areas.

"...if the current trends continue and the potential demand materializes, the possibility exists that there will be a great difference between the world need for forest products and the capacity of the forests of the world to provide them...this differential can only be avoided by stopping the decrease in

¹⁰Rappaport, Ray A. *El hombre et los bosques* edicion mimeografica, pp. 22-26.

¹¹In Mexico the population increases slightly more than 2 million people annually. In contrast the forested surface decreases by an estimated 200,000 hectares annually, according to the ex-subsecretary of the Engineering Branch; Cuauhtem Cárdenas in NOTISARH No. 4, April 1979.

forest area and managing the forests as they should be, by cutting more, by achieving a more complete and efficient use of all the products obtained from the forest, by creating and intensively managing prosperous and extensive plantations, and lastly, by ensuring that the benefits of forest utilization get to the communities that own them, live in them or work in them..." (Paragraph 24 of the Declaration of Jakarta Eighth World Forestry Congress.)

The forest plays an important, altogether indirect role in the production of food, through the regulation of waters, erosion control, as a supplemental source of forage in times of drought, in addition to generating employment and producing wood and other forest products. However, an indirect function in the production of food is not enough; it is necessary, in many cases, to create a wider concept of multifunctional forest activity which embodies more direct production of food, such as wildlife.

In the last decades, droughts, floods, and deserts have increased. This tendency will increase if governments do not proceed with a good management program including reforestation. The droughts and accelerated desertification in Africa, Asia, and Latin America have caused loss of life, along with the misery of millions of people.

The growing scarcity of firewood caused by population pressure, along with the reduction of the forests and the increase in energy prices, has produced an "energy crisis for the poor" which has come to affect 1,500,000 human beings, lowering their already low quality of life. The burning of vegetative residue and dung translates into a loss of fertility and consequently a negative effect on the production of food.

According to the 1970 Census data, 21,252,909 Mexicans still used firewood or charcoal as their basic fuel. It is also estimated that the minimum consumption of firewood for a rural family is 10 kilograms per day, or 3600 kilograms per year. For 21.25 million Mexicans (4 million families) the consumption of firewood and charcoal is 12.4 million tons annually. It is desirable that forestry programs assign a high priority to the production of firewood in appropriate places associated with agriculture and with complete cooperation of the rural populations.

For these same reasons, it is very important to optimize the use of forest residues from logging as well as forest industries. In this context, forests acquire additional importance as alternative sources of energy.

Especially critical is the situation in the tropical jungles of the world which are reduced constantly in quantity and quality. Increased cutting of the best wood for exportation has created a damaged and poor quality forest, which has created

serious human and ecologic problems, such as cut-and-burn agriculture in tropical zones. This has caused the large-scale destruction of forested and agricultural lands. This constitutes an urgent need for the restoration of productivity in these deforested areas.¹²

In the face of so many and such severe problems, we need to begin a global policy of forest management, a reorganization of the industry, the application of new technologies for utilizing the thin branches that are now lost, and the utilization of other species which are now not used or are under-used.

The utilization of the forest resource should have as an objective an increase in welfare, particularly of the communities that live or work in the forest, and in general of the entire population of the countries possessing the resource.

In spite of the fact that the large forest companies are fundamentally capital-intensive, forest activity is generally labor intensive, as small industries usually are. Although it might be important to mechanize a few activities, the important role that forests can play as generators of employment seems to indicate that it would be convenient to deliberately conserve, at least in the short run, the labor intensive quality of forest activity. More modern and sophisticated technologies could be justified in the future if the utilization of the forest resource accelerates rural development.

The function that certain manufactured forest products, other than wood, can have on the generation of employment and the betterment of the quality of life is of fundamental importance.

We must promote human resource development programs oriented toward the utilization of the forest and, in doing so, increase employment opportunities for women in forest activities.

¹²The National Clearing Program, which has operated officially in Mexico with Government backing since 1972, has cleared 114,000 hectares for agriculture and 423,000 hectares for tropical cattle production, having burned and destroyed 26.8 million cubic meters of wood in the five years of activity of the program. This is almost as much as the 28 million cubic meters reported as the usable wood production of the country in the same period (Magazine: "Mexico y sus Bosques," April, May, June #2, Page 5. Article by Ruben Castillo Frago). To this must be added the average of 5,000 forest fires annually in the country, according to data provided by the Department of Forest Fires of SAFH, and the 8 million cubic meters of wood which is extracted clandestinely, most of which is destined for use as firewood or charcoal. Additionally, overgrazing and agriculture also constantly affect the forested area of the country, constituting, together with the other factors already mentioned, a constant reduction of the national forested area.

The development of scientific forest research, the interchange of information, the development of technologies, and more scientific-technologic aid on the part of developed countries to underdeveloped countries is recommended.

Up to here, the ideas are from the "Declaration of Jakarta." This general perspective of what signifies the forestry problems of the world, and which is, although with regional variations, also applicable to Mexico, formulates the characterization of the national problem in the field.

THE IMPACTS OF NATURAL RESOURCE MANAGEMENT POLICIES ON THE NATIONAL ECOLOGY

The politics of this field have produced a growing conflict between the rural population inhabiting forested areas and the concessionary companies of forest utilization. Because they cannot directly take advantage of their resources and receive only meager cutting rights, the people adopt an attitude against the forest use of the soil. Since this use is lost to the people by being dedicated to agricultural or cattle-producing uses, the owners or legal owners of the lands try to recuperate for themselves the productivity of the lands they own. This has generated a growing hostility which extends from the extreme cases of intentional burnings to passive resistance through indifference or irresponsibility for what occurs in the forest.

On the other hand, and as an answer to the agricultural crisis throughout the country, there is talk of "widening the agricultural frontier." Generally, this expansion is planned at the cost of the tropical jungles, already punished too far by the expansion of grazing lands and by the slash-and-burn agriculture of the rural people. What is new is that this step is being determined from the planning centers which have not considered that, although the million hectares that they will subtract from the forested area might represent a short-term increase in production, in the long run, it will have negative repercussion because of the deterioration it imparts to the ecology.

The statistics on the ecological deterioration of the country are truly alarming. According to the data of the General Directorate of Soil and Water Conservation, the totally eroded area of Mexico was close to 30,728,000 hectares in 1978, and represents 14.99 percent of the national area. The area in an advanced stage of erosion covered 52,173,000 hectares (26.16 percent). The area of moderate erosion covered 46,742,000 hectares (23.96 percent). Only 34.89 percent of the country (66,746,000 hectares) was free of erosion or suffered from only moderate erosion.

We are speaking, without the benefit of rigorous studies, of the desertification of 100,000 to 200,000 hectares of land a year. Desertification occurs, not only in the arid zones, but throughout the country in areas of moderate and even good climate. Hillside agriculture, seconded by overgrazing, has been completing the work begun by deforestation.

The forest problem is also inscribed in the context of the two great differences which polarize day by day the conflict established within the framework of agricultural production, and around the two alternatives, the capitalist model, and the rural model.

Without a doubt, the forestry section has opted for the capitalist model, opting for short-run profits, and sacrificing those of the long-term and, of course, imposing high social and ecological costs whose impact is much stronger in the capitalist model than in the rural. This trend will be difficult to correct given the interests involved: bureaucratic corruption and the general lack of an ecological conscience.

We are of the hypothesis that the trend can only be corrected by promoting a rural model, in which it is the inhabitants of the forest that benefit from the forest products they are now denied. Only a popular rural movement, revindicating its right to forest products and organized for forest production, can force a change in the current policies in this field.

Ecological Planning in Land Use¹

Arturo Gomez-Pompa₂
Silvio Olivieri Barra²

One of the most important conflicts that arises between political decision makers and ecologists is the inadequate utilization of ecologic criteria in the assignment of priorities for soil and resource use in the different geographic regions of our country. It is a common occurrence that forest or agricultural soils are dedicated to grassland, rangeland soils are dedicated to agriculture, and agricultural soils are dedicated to urban use. Criticisms of the deficiencies in the assignment of different uses to various types of soils have come from several sources and are frequently conflicting. The "vocation" of soils is talked about insistently with little idea of what this concept actually means. Superimposed on all of these discrepancies are the opinions of ecologists, biologists, and conservationists who demand the creation of national parks and biological or ecological reserves. This group presents its own criteria for the possible selection of uses for the land and its resources.

Faced with this conflict of opinion, the state and federal governments have opted to not plan at all and to allow the different groups to continue in their course. Eventually, the force of the most economically or politically powerful, the personal opinion of the governors or local decision makers, or the force of public opinion orients government in one direction or another. Sometimes, it is not even possible to ascertain what variables were or were not taken into account in a given decision. Given the results of this policy, which have not been good, the Federal Government decided to organize all existing information necessary to obtain a more solid foundation on which to base land-use planning decisions.

As a means of obtaining this information, several governmental agencies were created. The Commission of National Territorial Studies (Comision de Estudios del Territorio Nacional, CETENAL) took up the task of mapping the lands of Mexico ten years ago, and produced a very important series of climate, geology, topography,

and soil-use maps. A parallel activity, perhaps motivated by other reasons but which ran in the same direction, was the creation of the National Commission for the Determination of Grazing Use Coefficients (Comision Nacional para la Determinacion de los Coeficientes de Agostadero de la Republica Mexicana) for evaluating the potential grazing lands of the country and determining the minimum area necessary for the support of one head of cattle. A further action was the creation of a National Forest Inventory, which also had the objective of mapping the forest resources of Mexico. The creation of the Directorate of the Synoptic Agricultural Map (Direccion de la Carta Sinoptica Agricola), a dependant of the Secretary of Agriculture and Cattle Production, and formerly of the Secretary of Agriculture and Hydraulic Resources, also took upon itself a cartographic study of the different geographic zones of the country producing the regional soil maps that complement the work done by CETENAL, now known as DGGTENAL (Direccion General de Geografia del Territorio Nacional). Other activities in the same direction, perhaps less well known, have been the work on soil fertility assessment, the agricultural, cattle, and forest censuses, and the mapping work done by state governments, universities, or ecological research centers of the country.

All of these activities indicate that there was concern to obtain basic information about the national land surface, with the idea that this information would eventually serve as a decision-making base for the better use of the different soils and resources of the country.

However, after almost two decades of activity along this line, we find ourselves with the dilemma that decision-making problems for better soil use prevail in spite of the current available information: In addition new organizations are still being created with the illusion that they are the ones to offer the final solution to the problem. As an example of this, we have the formation of the National Commission on Arid Lands (Comision Nacional de Zonas Aridas, CONAZA), the National Hydraulic Plan (Plan Nacional Hidraulico), the Tropical Development Plan (Plan de Desarrollo del Tropico), and the creation of the Rainfed Agricultural Districts (Distritos de Temporal), which, together with the old watershed commissions, such as the Papaloapan Commission, The Balsas Commission, the Grijalba Commission, etc., try to regionalize soil and soil resource decision-making with the idea that a regional focus can be more adequate for this objective. Obviously, there have been great advances in many of these areas but, the overall

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²National Institute of Research in Biotic Resources, Xalapa, Veracruz, Mexico. General Director and Head of Ecological Land Use Planning Program, respectively.

objection of obtaining an ecologically sound planning program for soil resources and land use has not been attained.

Currently, the problem is of such a magnitude that the process of deforestation, erosion, siltation of reservoirs, rivers and lakes and the growing loss of tillable soils is, without a doubt, one of the biggest problems our country will face in the future.

It is necessary to mention that the problem of land use planning becomes very complicated in a country like ours in which there is almost complete liberty of land and soil resource use and where the only legal instruments available to the state are difficult to use on such a confused and hard to define problem. How can a government punish a poor rural peasant who, to survive, has only the alternative of destroying a forest and using forest soils for inefficient agricultural uses? How can a government change a city like Mexico City, established many centuries ago with an urban-industrial infrastructure, because we now know it to be completely inadequate? In fact, many of our current problems are nothing more than the accumulation of past errors which have grown to such a magnitude that their solution is very difficult and occasionally impossible. This is especially true in a country like ours where the individual liberties which are guaranteed by the constitution, are frequently the source of the problem affecting the resources which are the heritage of our country.

Evidently, this problem is not exclusive of Mexico, nor of economically similar or underdeveloped countries, but also of capitalistic as well as socialistic countries and economically mixed countries. Perhaps, the consequences of poor planning are simply more evident in poor, developing or underdeveloped countries.

After presenting this gloomy panorama of ecological land use planning, we would now like to examine a few existing alternatives which we have been developing at our Institute. We expect that these alternatives will start us in a new direction in the more rational and conservationist use of all our renewable natural resources.

The essence of this entire process lies in identifying who shall make the decisions and what will be the instruments available for making these decisions. In Mexico, there is now a great diversity of decision makers on several levels. The rural farmer decides which crops he will plant in a given year and whether or not to cut a new area for more crops. The agricultural bank authorities decide what kinds of credit to approve in the next year and which will have priority in relation to investment security or other factors. The state governments set their own policies and priorities, while the federal government sets national policy in relation to food and other product production and soil, water, and biotic resource conservation.

Within these extremes, the importance of the decision is decidedly very different. For instance, the decision a small group of people might make to

construct a reservoir will greatly affect the resources and environment of a large region, while the impact of the decision of a local farmer to open up a small parcel in forested soils will be more limited in scope. However, the aggregate of all these decisions forms the national panorama of our natural resource and land management.

Obviously, such a decision-making problem has no easy solutions. It would be wonderful to have a cartographic method that could provide each interested party with the ecological criteria for the best use of its resources and soils and which could be implemented on a national level.

In fact, the cartographic works of the past tend in this direction, but they haven't been used as such because it is practically impossible to assign one single alternative to each site and have the alternative be ecologically, economically, socially, and politically sound. For example, we could identify a marshy area as very important to conserve from the point of view of flora and fauna, but, if oil is discovered in this area, the economic factor will obviously prevail over all conservationist arguments, whether we like it or not. For this reason, the economic, social, and ecologic costs of alternative action as well as possible solutions to problems that might arise with conflicting resource and land uses, must be taken into account.

With this as a background, through our research program on Land Use Planning, we have tried to develop methods that can be used by different types of decision makers, and that enable the users to evaluate the different costs of specific decisions by themselves, aided by the data and analysis tools that are provided. In this way, the decision maker can judge which is the best decision, without requiring that scientists be called in to make the final assessment as is usually the case.

The idea is essentially as follows: given a range of environmental conditions, each ecological zone can be used for different purposes with varying short- and long-term consequences which will include economic, social, and environmental aspects, and quality of life. Each use implies a transformation in the great majority of cases (with the exception of nature conservation, which also carries an investment and maintenance cost). For example, the decision to open a forested region up to agriculture, depending on the type of agriculture involved, will have an economic cost (such as the investment necessary for erosion protection if the soils require it) and an ecological cost, which could be the loss of genetic material necessary for the re-establishment of the former forest.

Many of these costs are not measurable in the same units and are difficult to compare. For example, what is the ecological cost of clearcutting one hectare? The cost could be very high if the area to be cut is the only one left in the region, or very low if it represents only a fraction of the ecosystem. How do you assign a numerical or monetary value to this cost? It would vary depending on the interest involved, i.e., the government, the people, and the landowners. It would also depend upon the quality of life expected by the society involved

aesthetic or recreational value). In any case, it is the decision maker who must evaluate the pros and cons of each alternative on a global level before deciding.

This evaluation is by no means obvious and, due to the complex inter-relationships which are involved, the evaluation of the regional impact of a decision or of a series of decisions requires not only available data but a methodology which takes into account the complexity of the system.

To develop this methodology our group decided several years ago to choose the center of the state of Veracruz as a pilot area for this research. This area is a densely populated region of approximately 4,700 square kilometers, which includes a variety of ecological zones, a long tradition of rice, and specific ecological, environmental, demographic, and economic problems. The steps taken in this research have been the following:

1. An exhaustive review was made of all the information available about the region: climate, soils, agriculture, cattle raising, forests, vegetation, water, economic factors, prices of crops, crop yields, ecological systems of cattle and agricultural production, etc. Fortunately, the region, like many other regions of Mexico, has been well studied, and there is an abundance of information which has been gathered and which gives us a primary information base to work with.

2. Parallel to the gathering of this information, the principal ecological zones of the region were identified. For this, two dimensions were used; first, a macrodimension, which involved the selection of seven large land systems which were divided into 33 subregions (landscapes) using primarily climatic and physiographic criteria. The other dimension, on a micro level, includes the classification of distinct ecological zones called terrestrial units, or land forms, within the subregions. For example, there could be an area x subdivided into slopes, hill tops, valley bottoms, etc. These units were mapped using satellite imagery, aerial photographs, and field surveys. The idea is that using this classification system, any site within the region can be easily classified.

For each of these units, an attempt was made to relate all of the information available from the literature, statistical data, and field surveys to determine the different uses which had or could be planned. Potential erosion data was included in this as a function of climatic and soil data and especially, soil fertility and the agricultural history of each zone. Given the importance of the productive potential of each unit and the impossibility of being able to count on prior information on productive potential, corn was chosen as an indirect indicator of the productive potential of all zones as it is the only cultivated crop found in practically the entire region.

As a result of the large quantity of data that had to be analyzed, it was decided at the beginning of the project to use computer simulation and optimization techniques to condense the information into a form that could be used in the planning

process. Linear programming as well as goal programming was used, and the method was tested by playing simulated planning games on the entire region.

In a simple way, what our method does is as follows: a decision maker, which could be many different types, can go to a computer terminal and, for a specific region identified by him through cartographic methods and ecological profiles, ask the computer, for example, what would be the regional consequences of changing a coffee plantation into grazing land. The answer would be given as the cost of the transformation, the expected investment and profits in the short-, medium-, and long-run, the amount of labor generated, expected erosion level, etc. With all this information, the decision maker will be the one to decide whether or not to continue with the plan or change it for another that would be better for him and the community.

In the case of our application of the method to the center of Veracruz, this type of model has allowed us to study the carrying capacity of the region under different alternatives or scenarios, and study the regional impact on land use as a function of the demands made by a growing population.

In effect, the study area had 603,000 inhabitants in 1978, 48 percent of which were urban. Our projections show that this population will double by the year 2,000 with 1,190,000 inhabitants, 63 percent of which will be urban. The level of food consumption of an urban resident, according to a study done in the region, is 2.5 times that of a rural inhabitant. Then the pressure exerted on the natural resources of the region will grow explosively in the next years. Therefore, it is important to understand more deeply this problem as well as the possible alternatives: more technology, mechanization, education, etc. Which of them will be more relevant, or will be the most limiting factor for an increase in production in the region? Also, what will be the ecological cost associated with each one of them?

For a particular scenario, the model integrates, for example, the optimum use of the land as a function of the objectives set by the user, as well as the demand and distribution of labor, the amount and distribution of erosion, the amount and distribution of profits generated, etc. A great advantage of our method is that some of the factors are variable, such as the price of crops or grains, since the economic factor is the crux of decision making in practically all of the models. For example, a rise in the price of fertilizer can result in certain crops which require large quantities of fertilizers not being economically feasible. While others that do not require fertilizers being feasible. With the methodology, the fragile zones can be analyzed.

In this very condensed form, we have presented to you the contributions that the Federal Government, through our Institution, is making toward a more compatible process of economic development of our country with the utilization of

ecologic and scientific criteria which, in a free environment, can organize or punish licentiousness in the use of natural resources. The method is now available and can be adapted to almost any part of the Republic.

In conclusion, we wish only to say that the work up to now indicates that the road to ecological planning of land use in our country may lie in methods like the one we have been developing. It should be noted, however, that this implies a new assessment of the problem of natural resource

planning and a fundamental change in decision making with respect to what we have had in the past. We think that this is a good doorway into the future.

This focus is also being followed, with some differences, in other countries with which we have had experience. Our work is a Mexican contribution to the MAB program of UNESCO, and we have shared experiences with the MAB committees of the United States, Australia, Venezuela, and Argentina.



Figure 1.--Improperly used land can reject human societies.



Figure 2.--The once great have fallen.

Grazing, Natural Resource Policy, and the Biosphere Reserves¹

Warren P. Clary²

EXPERIENCE OF HISTORY

Civilized man, it is said, marched across the face of the earth and left a desert in his footsteps. Although this is an exaggeration, civilized people have greatly damaged most of the lands on which they have lived for a long time. This damage has been a primary cause for the decline of societies in older, settled regions of the world, and a major factor in historical trends.

History writers seldom note the importance of land use. They have not recognized that the destinies of most societies were determined largely by the way the land was used (fig. 1). While recognizing the influence of environment on history, historians failed to also recognize that people usually changed their environment. Many poor peoples of the earth are poor today because their ancestors wasted the natural resources on which present generations depend.

Historical records of the last 6,000 years show that civilized people, with few exceptions, were never able to continue a progressive society in one locality for more than 30 to 70 generations (notable exceptions were the Nile Valley, Mesopotamia, and the Indus Valley). The average

time span was 1,000 to 1,500 years. After a few centuries of growth and progress, in most situations civilizations declined, perished, or were forced to move to new land. These civilizations had declined in the same geographical areas that had nurtured them mainly because the people ruined the environments that had helped them develop the civilizations.

Civilized people ruined the environment by cutting down or burning the forests, by denuding the grasslands through overgrazing by livestock, by killing much of the wildlife and fishes, and by permitting erosion to rob the land of productive topsoil. They allowed eroded soil to clog the streams and fill reservoirs, irrigation canals, and harbors. In many cases they wasted easily mined minerals. Thus, the civilization declined or the people moved to new land. As many as 30 major civilizations followed this road to ruin. Across Asia and in Europe and North Africa are seats of former leading civilizations that are now among the backward areas of the world (fig. 2). Many of these lands from whence our western civilization arose were once productive but are now largely impoverished.

The misuse of natural resources by overgrazing and other exploitation is not limited to ancient peoples. A more recent example is the arid and semiarid western rangelands of the United States. These were exploitatively grazed in the late 1800's and early 1900's. By the 1930's western rangelands had been depleted to the point that the grazing capacity for domestic livestock was less than one half of what it had been when in virgin condition. Valuable, palatable, and nutritious forage plants disappeared and were replaced by plants that were often unpalatable, poisonous, or

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²Principal Range Scientist, USDA Forest Service, Intermountain Forest and Range Experiment Station, Ogden, Utah, located at Shrub Sciences Laboratory, Provo, Utah, USA.



Figure 3.--Floods that had occurred soon after excessive grazing of mountain watersheds exceeded any of recent geologic time.

unreliable annuals. Also, accelerated soil erosion on seriously affected areas destroyed the ability of the site to attain its original productivity. All this reduction of livestock carrying capacity occurred within a 20 to 50 year period, and, in some cases, in as little as 10 years.

A more specific example is in Utah. In the 40 years before 1930, floods increased all over Utah. Floods and mud-rock flows originating in mountain canyons apparently exceeded anything that had occurred there for thousands of years. Boulders weighing as much as 200 tons were carried into the valleys, farmlands were ruined, homes and lives were lost (fig. 3). Soils, with depths equivalent to that which had developed in the 8,000 to 10,000 years following the recession of pleistocene Lake Bonneville, were lost in a few years. Investigations revealed that this serious situation had occurred soon after settlement in the latter portion of the 1800's.

Many other examples exist in the western United States. Often serious flooding and erosion began within 15 years after settlement and heavy grazing with sheep and cattle.

Human degradation of the land is called "desertification." The most obvious example is in North Africa where abuse of the vegetation has allowed the desert to continually expand. The problem is not limited to North Africa, but occurs on all major land masses. This means the long-run survival of our civilizations may be at stake. The eroded lands upon which many early civilizations were based now support only about one third the population they supported in ancient times. In addition, many of these people live in a rather impoverished condition compared to much of the world.

Will our modern civilization begin to practice true and full conservation, or will our conservation efforts be like those of all the ancients--too little and too late? The habit of destroying the natural resource base where people live is as old

as civilization. It will not be easy to change our ways. The odds favor a continuing steady decline in the basic stock of topsoil in all our countries. Only science aided by proper natural resource policy can sidetrack civilized people from this historic pattern.

NATURAL RESOURCE POLICY

The proper use of natural resources must begin with knowledge--knowledge of what must be done to preserve the natural resources upon which we all depend, and knowledge of how to use the land's productivity in an effective manner. The application of natural resources knowledge comes in part through natural resource policy. We must be aware, however, that the simple existence of a policy does not guarantee appropriate use of the land. For example, natural resource policy played a role in the improper practices of early settlement years in the western United States. Among other things such policies:

1. encouraged a fragmented ownership pattern that made proper grazing management almost impossible;
2. encouraged plowing of lands too dry to farm; and
3. allowed unrestricted common grazing on public lands.

Improper use of the land was virtually assured when these policies were added to the early settler's lack of knowledge about arid lands and their pioneer philosophy that natural resources were nearly inexhaustible.

Since these early days, land use policies in the United States have generally improved--particularly as they apply to publicly owned lands. There has, however, been some vacillation between conservation and exploitation depending upon changes in public opinion, leaving natural resource policy in a continual state of change. Some of the stronger moves toward protection of the resource includes establishing Forest Reserves for watershed protection in the early 1900's, passage of the Taylor Grazing Act in the 1930's, and a number of environmental laws in the 1970's. During intervening periods, there were pressures to reduce the resource protection efforts. Currently, in the western United States, a movement called the "Sagebrush Rebellion" seeks to attain State jurisdiction over Federally owned lands. Many fear this movement could result in less protection for resources.

Many countries are working to develop knowledge and technology that would allow people to benefit from the limited productivity of arid and semiarid lands, while at the same time conserving the lands for future generations. Many of these efforts were described at the First International Rangeland Congress in August, 1978, at Denver, Colorado, USA, where information from 39 countries was presented. The combined social, political, and biological aspects of managing native grazing lands were given high visibility in this meeting.

An example of knowledge development encouraged by natural resources policy is the considerable research conducted on management of arid and semiarid grazing lands in the United States. Many Federal and State agencies and universities have research programs on the management of domestic and wild grazing animals, physiologic and ecologic requirements of native forage plants, and reseeding or other techniques for reclamation of areas depleted due to overgrazing, cropping, surface mining, or natural disasters. The application of the resulting knowledge has improved many Western United States grazing lands (fig. 4), although much additional improvement is necessary.

For those unfamiliar with grazing technology, excellent sources of information are publications from the Society for Range Management, an organization dedicated to proper management of native grazing lands. This international professional society is headquartered in Denver, Colorado, USA and has an active Mexico section.

BIOSPHERE RESERVES

How do the Biosphere Reserves fit into this picture? The concept of Biosphere Reserves involves a broad philosophy of conservation. The objectives of the reserves include:

1. to conserve communities of plants and animals for present and future use and to safeguard genetic diversity of the species;
 2. to provide areas for ecological and environmental study; and
 3. to provide facilities for education and training.
- Each reserve is to be a "conserved" area that can be studied.



Figure 4.--Depleted grazing lands can be restored.

Soil loss, especially as it relates to grazing, is often not as spectacular in other areas as it was in turn-of-the-century Utah. More typically, it has occurred slowly over longer periods. Thus, most people are not aware of the problem even though the productivity of the land may be decreasing each generation.

The Biosphere Reserves should provide those who set natural resource policy or who use the land with better understanding of the long-term dangers of improper management and knowledge of how to better manage the land for present and future generations.

Integration of Wildlife and Other Natural Resources Policies¹

Peter F. Ffolliott²

INTRODUCTION

In any country, wildlife resources must be managed in accordance with long-range policies based on knowledge derived from thorough biological research and on administrative practicability. Furthermore, in formulating policies, the impacts of wildlife resources management should be considered in a multiresource framework. Only within such a framework can an integration of land uses be achieved for wiser use and conservation of all natural resources.

To formulate wildlife management policies in a multiresource framework, fundamental concepts of sensible resource administration implemented to meet the local problems must be incorporated. Also, an understanding of how these policies can impact, and be impacted by, other natural resources policies is necessary.

FUNDAMENTAL CONSIDERATIONS

While not inclusive, the formulation of policies for the management of wildlife resources should be based, in part, upon the following basic concepts:

1. Maintenance or enhancement of the existing standard of living for a steadily increasing population requires maximum production of food, fiber, and minerals. The management of wildlife resources must be consistent with this need.

2. Maximum yields of wildlife resources, for both consumptive and nonconsumptive purposes, are dependent upon a well-advised land and water management program. Therefore, management practices conducive to maximum production of wildlife resources should be integrated with forestry, other natural resources, and agricultural programs.

3. Optimum populations of wildlife species depend, in large part, upon the maintenance of favorable environmental conditions and upon a balance between these populations and their environment.

4. Harvest and utilization of wildlife resources (in particular, of game species) should be determined by species abundance and reproductive

capacity in relation to existing habitats. Emphasis must be placed, if possible, on real or potential value, rather than on artificial values derived from custom or prejudice.

5. Wildlife management employs a variety of procedures to maintain (or otherwise modify) existing harvest and utilization practices. Since no single method is adequate, all methods should be used to the degree warranted by their proven value and utility. These practices include environmental control, regulation of harvest, refuge establishment, artificial propagation, stocking and predator control, etc.

6. All wildlife management should be based upon the findings of adequate biological research modified, if necessary, to reflect local conditions.

7. Sensible administration of wildlife resources depends upon the continuous services of all members of a well organized and cooperative professional staff. These staff members should be selected on the basis of both adequate training and professional competence, and they should have guaranteed tenure free of political interference.

8. Agencies and organizations administering wildlife resources should have complete discretionary powers for the setting of hunting seasons, bag limits, methods of harvest, etc.

9. The success of any policy or program for the management of wildlife resources can only be gained through the support of an enlightened public. Therefore, a program of education and publicity should be an integral component of any wildlife management plan.

IMPACTS OF WILDLIFE POLICIES ON OTHER NATURAL RESOURCES

Implementation of a policy for the management of wildlife resources can impact the use of other natural resource products and uses. These impacts should be recognized to integrate wildlife and other natural resource policies.

For example, harvesting regulation should be used as a tool to permit the highest possible take compatible with sustained yield determined by prevailing biological potentials and environmental conditions. However, continuance of a particular harvesting regulation policy may restrict forestry, other natural resources, and agricultural programs if these latter programs drastically alter the environment.

Refuge programs should be developed to protect vulnerable wildlife species from excessive hunting pressures. Such programs must be flexible in nature

¹Paper presented at an International Seminar on SOCIAL AND ENVIRONMENTAL CONSEQUENCES OF NATURAL RESOURCES POLICIES, WITH SPECIAL EMPHASIS ON BIOSPHERE RESERVES, held in Durango, Durango, Mexico, April 8-13, 1980.

²Professor, School of Renewable Natural Resources, University of Arizona, Tucson, Arizona, USA.



Figure 1.--A habitat improvement practice designed to increase food for wildlife in the southwestern United States.

so that they can meet changing needs. Refuge programs should not be administered in such a manner as to "lock up" wildlife resources which, at the same time, could limit utilization of other resources.

Wildlife is a product of and dependent upon a suitable environment. In areas where deficiencies in food and cover (either protective or thermal) are limiting, habitat improvement practices may be necessary. It is important that, if implemented, these habitat improvement practices do not restrict the flow of needed products and uses derived from other resources (fig. 1).

IMPACTS ON NATURAL RESOURCES POLICIES ON WILDLIFE RESOURCES

Just as the implementation of wildlife management policies affects other land and water management programs, these programs impact the administration of wildlife resources. To insure wildlife management in a multiresource framework, an understanding of these latter impacts must be incorporated into the policy formation process.

As suggested above, forestry, other natural resources, and agricultural programs may have to be restricted if they alter the environment to the extent that maintenance of a harvesting regulation policy is not possible. But, in certain situations, products and uses derived from these programs can be of more importance than wildlife resources in a local or regional economy. This being so, harvesting regulations will have to be brought into

"balance" with the other needs.

Similarly, refuge programs which protect vulnerable wildlife species from hunting may also limit the utilization of other resources. If demands for these other resources so dictate, policies relating to refuges may have to be redirected.

Whether designed to or not, land and water management programs often change wildlife habitats. In many instances, a complementary result of these programs is the enhancement of habitat conditions. However, some programs can have detrimental consequences in terms of food and cover available for particular wildlife species. In either case, an analysis of "trade offs" among resource products and uses is necessary to integrate wildlife and other natural resources policies.

EDUCATIONAL POLICIES

As previously mentioned, the success of any policy relating to wise use and conservation of natural resources depends upon the support of the people to be affected by the policy. To a large extent, this support can only be obtained through effective educational programs. It is here where the framework of Biosphere Reserves can play an important role in providing a setting in which alternative wildlife management policies can be evaluated prior to operational implementation, and then the best course of action can be selected. With specific respect to wildlife resources, certain educational policies should be encouraged:

1. The people should be informed of the reasons for and the problems involved in wildlife management programs, particularly in the context of multiresource utilization.
2. Educational programs should emphasize that the mechanisms controlling wildlife populations are extremely complex, that research investigations of these mechanisms are in order to establish a basis for efficient management of these populations, and that continually changing environmental conditions may require new and changed management procedures.
3. The findings of research should be published (or otherwise disseminated) promptly in the interest of advancing wildlife management, locally, regionally, and nationally.

When formulating wildlife resources policies, fundamental considerations, impacts of these policies on other natural resources, impacts of natural resources policies on wildlife resources, and educational policies must be integrated. Through this multiresource framework, an integration of land uses for wiser use and conservation of all natural resources can be achieved.

Wildlife Management:

White-Tailed Deer in La Michilia Biosphere Reserve¹

Sonia Gallina and Exequiel Ezcurra²

INTRODUCTION

Wildlife is a natural resource that has never been fully appreciated nor adequately utilized in Mexico, and it has suffered severe deterioration in many parts of the country. We feel that wildlife conservation and management, more than a legal problem in need of more regulation, is a cultural and socioeconomic problem that has led human populations to a poor use of natural resources often against their own traditional customs and uses. Only by including people into the natural resource protection programs, so that they understand that they have a resource in wildlife that must be used over the long term, can we establish a true protective policy.

The Institute of Ecology in Mexico City, recognizing the urgent need to conserve fauna, has taken great efforts to determine the best use of this resource. This is why research in the Biosphere Reserves of Durango is directed toward analyzing the functions of ecosystems. We need to understand the biology and ecology of the different species, population dynamics, and interaction with the other components of the ecosystem.

THE STUDY

On La Michilia Biosphere Reserve in the south, south-east of Durango since 1975, we have been studying the white-tailed deer (Odocoileus virginianus), an important game species for the country and a species having a large distribution in Mexico. The objective of this work is to study the population behavior as it now exists on the Reserve, and to establish a general mathematical model to predict changes in the population and devise better management techniques.

¹Paper presented at an International Seminar on SOCIAL AND ENVIRONMENTAL CONSEQUENCES OF NATURAL RESOURCES POLICIES, WITH SPECIAL EMPHASIS ON BIOSPHERE RESERVES, held in Durango, Durango, Mexico, April 8-13, 1980.

²Biologist and Master in Science, Institute of Ecology, Apartado Postal 18-845, Mexico 18, D. F.

Food Habits

The first step was to determine the white-tailed deer diet and its seasonal changes, using microscopically analyzed deer pellets and identifying the eaten plants by the epidermis which remains throughout the digestive process. The results published by the Institute of Ecology in 1978 were: a major part of the diet consists of bushy plant species (51 percent), followed by tree species (32 percent), and grains (2 percent) and the most common species eaten are: mistletoe (Phoradendron bolleanum and P. villosum), manzana (Arctostaphylos pungens), other species of Arctostaphylos, gatuna (Pithecellobium leptophyllum), buckthorn (Condalia hookeri), junipers (Juniperu deppeana and J. durangensis), oaks (Quercus spp. and madrone (Arbutus glandulosa).

The diet of white-tailed deer changes seasonally on the Reserve, according to plant availability. In the summer rainy season, deer eat many herbaceous plants, most of which are annual. This preference is related to forage quality; growing species have a higher nutritive value and are more palatable for the deer.

Because of the number of plant species consumed (135 individual species), deer are considered to be generalist herbivores. This is an advantage for the species because it permits it to more easily adapt to vegetation changes (i.e., they are not too drastic) and to live in a variety of habitats as long as food and cover are available.

On La Michilia Biosphere Reserve, deer feeding areas are well defined, located on the high mesas and slopes where an open pine-oak forest develops with distinct dominant species and a good growth of bushes and herbaceous plants which are ideal as a dietary supplement. Besides forage, deer find cover in these areas where it is easy for them to perceive danger at great distances and flee more quickly from their predators (e.g., puma, coyote, bobcat, and man).

The white-tailed deer on the Reserve must share their habitat with cattle which constitute the most important economic activity of the region. This is why it is important to learn the basic aspects of the feeding behavior of the two species of ruminant herbivores to determine their relationship as possible competitors for the food resources in the ecosystem they inhabit.

With respect to the feeding habits of cattle, we have only made a few direct observations. We hope that this year we can quantitatively study the diets of both herbivores to determine the real level of competition.

According to our observations to date, cattle eat mainly grasses (54 percent of all plant species eaten) and forbs (24 percent), and consume bushy and tree species mostly during the dry season. Due to lack of detailed quantitative information on the dietary habits of cattle, a first approximation of the overlap between the diets of cattle and deer has been obtained by calculating the proportion of plant species common to both diets for the dry and wet seasons, according to Lorenzen's formula:

Plants	Dry Season	Wet Season
Grasses	0	0.53
Forbs	0	0.34
Bushes	0.24	0.38
Trees	0.18	0
Total	0.13	0.35

These data, based on a simple plant species list, seem to indicate little overlap between the two diets, especially during the critical season. Competition for food can be analyzed more precisely once quantitative information on the diets of both species is available.

It seems logical, however, that competition is not very high if we consider the following facts:

1. In spite of the fact that cattle eat some bushy and tree species, which are basic to the diet of the deer, these plants are abundant on the reserve.
2. Cattle are kept on pastures that are rotated every year, while the deer roam freely.
3. Cattle receive dietary supplements of "harinolina" and oats during the critical dry months.
4. The diet of cattle is based on grasses, while that of the deer is based on bushes and trees.

According to available information, it is possible to affirm that the white-tailed deer is an exploitable species in cattle ranching areas similar to La Michilia. With the establishment of combined management of the two species, white-tailed deer can be a source of extra income for ranchers and ejido members.

Population Evaluations

Every wildlife population management and research project must include the periodic evaluation of animal numbers. This is essential to establish

management standards, bag limits, hunting seasons, etc. In the case of La Michilia, the problem is complex because capture introduces a higher mortality factor in a small population, and because the abrupt topography makes direct observation or capture extremely difficult.

For this reason, it is necessary to develop methods of sampling and population analysis that conform to these limitations. On La Michilia, we have used two approaches to the problem: the evaluation of deer pellets and the evaluation of browse plants eaten by the deer. The first is more objective and lends itself to a more vigorous statistical analysis. The second method has given lower estimates because investigators often underestimate the parts of the plants that have been eaten; this method serves as a form of check and verification of the results of the first.

To calibrate the methods for La Michilia Biosphere Reserve, we used a pen with a small number of animals. In this way, it was possible to verify the accuracy of the pellet data and the adequacy of the sample. This method of analysis has provided valuable information on the deer populations and yielding more data than what we initially expected. The most important results are as follows:

1. The distribution of pellet groups in the field is clumped, which indicates a marked habitat preference by deer, a well-defined social behavior, or both simultaneously.
2. The clumping of pellet groups shows a marked positive density-dependence in time as well as in space. This implies that population sociability increases with density. With low density, deer are less gregarious; with high densities, they are more grouped together.
3. Deer population densities on La Michilia tend to decrease. This could be due to: illegal and indiscriminate hunting in the areas surrounding the Reserve, a cycle in the dynamics of the population, or migration away from the area. There are still not enough data to clarify this point; our next investigations will be directed toward this problem.
4. Among penned animals, there was a marked relationship between pellet size and animal age. Based on this evidence, we determined the age classes of the penned deer at La Michilia, and determined that predictions are valid. This allowed us to estimate the age classes of the animals in the field. These demonstrated the characteristic oscillations of a population which is unstable in its age distribution.

Although research is still in progress, it is possible to extract two conclusions from the population studies:

1. It is possible to use indirect methods to evaluate the state of the populations of animals

with an acceptable level of precision. This is important in the philosophy of resource management. On La Michilia, we have replaced capture sampling methods with fecal analysis and browse plant analysis. The lower accuracy of the indirect methods can be compensated, in large part, through larger sample sites and more elaborate statistical analysis. This method of investigation permits the study of a small population without altering its structure. On the other hand, it confers more authority to the opinion of the researchers when they demand conservation of the natural resources.

2. The deer population on La Michilia Biosphere Reserve demonstrates a tendency to decrease with oscillations in age structure which are greater than can be expected in stable populations. We suspect that there is either intense migration from the area or an extraordinary cause of mortality. Migrations could be related to the availability of water during the dry season; the mortality could be related to illegal hunting. While the causes of the decrease are being studied, more control of hunting in the surrounding areas of the Reserve is needed until the deer population returns to an exploitable level.

Integral Development of the Rural Communities¹

Armando Ochoa²

INTRODUCTION

For a Biosphere Reserve such as La Michilia, conservation, ecologic research, and the acquisition of technical and scientific personnel with the knowledge necessary to manage the Reserve is not enough. The resolution of social and economic problems of the human settlements in and near the reserve must also be given high priority.

The most needy residents of the towns of the periphery of La Michilia Biosphere Reserve, of which San Francisco de Mezquital, Suchil, Vicente Guerrero, Nombre de Dios, and Villa Union stand out, together with the heads of many other municipalities with multiple needs, have been pressuring the Agrarian Authorities to divide the forest. Establishment of the Reserve has opened a new door, providing these people with the opportunity to seek and find valid alternative solutions to their demands for social justice. Until now, the only palliatives for these people have been principally migration to the big cities or enrollment into the ranks of the undocumented.

The most serious damage caused by the loss to a region of its most capable and willing element is through decreased farm and related production, creating discouragement and frustration in those who stay in the communities.

Of the slightly more than one million hectares which represent the total land surface of the five municipalities mentioned above, only 6.4 percent is used for agriculture; however, only a much smaller percentage is appropriate for that activity. In the municipalities of Mezquital and Suchil, there are large forested areas, but their exploitation is weak and technologically lacking.

In the valley which includes Suchil, Vicente Guerrero, and Poana, thick brush, mesquite, huizaches and prickly pear predominate. In the best of cases, these lands can be used as pastures for cattle, horses, sheep, or goats. Livestock production in this valley is, in general, a marginal activity and is economically important.

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²Director of Graduates and Scientific and Technological Investigation, National Polytechnic Institute, Zacatenco, Mexico 14, D.F.

Of those lands destined for agriculture, one-fourth is irrigated and used mainly for the cultivation of beans, chiles, and wheat. On the seasonal (unirrigated) land, only corn and beans are cultivated, with a productivity per hectare of 800 and 700 kilograms, respectively, quantities insufficient for the consumption of even one family.

According to the 1970 census, the economically active population of these municipalities was only 21 to 25 percent of the total, most of which was in agriculture, livestock production, and silviculture. Only 8 percent of this economically active population received more than the minimum wage.

The vast majority of the approximately 150,000 inhabitants of these municipalities demonstrates visible deficiencies in diet, housing, dress, and education. Because of malnutrition and the lack of hygiene, disease (especially in the form of parasites and infections) is a serious problem affecting a large part of the population.

Up to now, I have mentioned only the need for permanence of the Reserve in relation to the conditions of the landless rural poor, but we must not forget that there are other pressures which are almost always more influential for the decision makers. These pressures come from those who see these areas as a source of easy and quick riches, or of private family diversion without a thought to the deterioration or exhaustion of the natural resources, and would, through the system, exclude the benefits from those who live on or near the area and who, in reality, have more right to them.

THE INTEGRAL DEVELOPMENT PROGRAM

The research program that the IPN has been managing since 1974 in the State of Durango (through its Center for Interdisciplinary Research for the Integral Development of the rural community, CIIDIR), is trying to raise the standard of living of the residents of the five municipalities around La Michilia Biosphere Reserve, as well as carry out the institutional objectives which gave rise to the Polytechnic Institute. This program is based on ecodevelopment, which will make it possible to attend to both material human needs and the preservation of the environment. At the same time,

the program methodology includes the five well-defined stages described below:

1. Develop a deep understanding of the regional problems, the manner of thinking of the people that live there, and their fears and aspirations. In other words, be totally cognizant of the social, economic, and political situation and of the real, actual, and potential possibilities for the development of the region.
2. Establish and rank (with the members of the community) the most viable solution alternatives.
3. Once the problem and a cooperative plan of action with the community are identified, begin the projects which appear to resolve the problems. This is done with clear objectives and precise fulfillment and timing goals, with emphasis on involving as many of the rural population, ranchers, and Ejido and municipal authorities as possible.
4. Consolidate the programs initiated in the third stage and complement them with the generation of agroindustries.
5. Integrate the activities designed to achieve the final objectives of the Program of Integral Rural Development. Those objectives are: creation of employment, production and distribution of food, integral health of the population, education, and the conservation of the environment.

The author, who is also the initiator and promoter of the first projects (along with some of the participating researchers) are natives of the region and have not lost contact with the people and their reality. We feel that we understand the problems of the people and are able to collaborate in the formation of options to provide effective solutions.

Through this understanding, and through discussions and analyses carried out in many meetings with ejido members, small land owners, businessmen, professionals, students, and political authorities starting with the State Governor, we arrived at the resolution that we must reinforce, through experimentation and various supportive works of the primary production activities, the following: agriculture, livestock production, fruit production, and silviculture. These activities constitute the base of the local and, in general, State economies and generate the few commercial and industrial activities of the area. The experiences and interests that the people, especially the rural workers, have in these activities permits us to establish communication with the people and, consequently, facilitates the promotion of technology, research, extension, consultation, and education.

More than five years have passed since we brought together (in Vicente Guerrero) a group of farmers, Ejido presidents, the municipal president of Vicente Guerrero, the representatives of several state governmental agencies (the General Directorate of Public Education, the Directorate of Development, and the Agriculture and Livestock Delegation), and some IPN researchers, to tour the

area. Several parcels and orchards near San Francisco Murguía, San Pedro Alcantara, Presa Santa Elena, Vicente Guerrero, and Gabriel Hernandez were visited. From the observations, comments, and recommendations that came up during the trip, a concrete idea with possibilities as a research topic was formed: the cultivation of strawberries for plant and fruit production. We had seen a family patch in San Francisco Javier with some plants producing fruit, and during conversations with Ejido members that were cultivating corn in Gabriel Hernandez, we were told that in the preceding years they had planted some strawberry plants which had dried up for lack of irrigation.

The cultivation of strawberries fits in very well with the goal of experimenting with a crop which would need much human labor, be of high yield, require some technology, and have industrial possibilities. In March of 1975, we established, near Francisco Murguía, a greenhouse on a quarter hectare of a small farm. With the progeny of the plants of that greenhouse, we extended the crop to a little less than a half hectare for fruit production (which began in April of 1976 and lasted until August of that year producing strawberries during the same period of the next year). In 1978, the Governor of the State helped us get a loan from the National Rural Credit Bank, and it has been renewed up to this date.

I have tried to give a detailed description of the procedure we have followed, using as an example only one of the studies. However, the rest of the projects that comprise the following programs: Introduction of New Crops, Use of Plants in Arid Zones, Integral Health, Agriculture, and Creation of Agroindustries, followed the same methodology.

RESULTS

Introduction of New Crops

In 1979, we produced almost 80 tons of strawberries and more than 6 million plants, with a yield of 12 tons of fruit and 600,000 plants per hectare. This year, we have 12 hectares in production and the harvest has already begun, with an expected production of 250 tons (approximately 23 tons per hectare).

The plants are sold to agriculturists in Zamora and Irapuato; the strawberries, since last year, are being marketed in Durango, Vicente Guerrero, Lerdo, Gomez Palacio, Torroen, Chihuahua, Monterrey, Mazatlan, Culiacan, and in neighboring towns, in the following forms: bulk fresh strawberries, destemmed frozen strawberries, and sliced frozen strawberries mixed with sugar.

The investment per hectare in this crop has been close to 100,000 pesos, of which more than 70 percent is paid as salaries for soil preparation, plants, insurance, picking, destemming,

packaging, transporting, processing, etc. More than 20 people have enjoyed permanent employment in the project. Eventually (especially in harvest time), we expect to employ more than 120, mostly women and children. These benefits are in addition to those resulting from the impact of the project on the economy and services of the area. The packages used in transportation are mostly of wood cut to the right size in an Ejido workshop in Salto, Durango and assembled in Vicente Guerrero. Each wood box costs 15 pesos and will hold 5 to 5.5 kilograms. In Constanca, baskets which are used to sell fresh strawberries are made.

All this, up to now, seems simple and may give the impression that it was done easily and effortlessly. However, it has been difficult, and, at times, it seemed that we could not continue. There were moments in which we wanted to quit and justify our work by saying that the responsibility of the scientist is only to arrive at methods that work and can be reproduced, not to train and organize the rural, technical and support personnel; least of all to take responsibility for marketing a perishable product in the face of larger competition (we had to compete with the strawberries of Irapuato and Zamora). All of this and much more we had to do; otherwise, our data would be filed away in theses or scientific or informative articles without having been realized as an economic benefit for the marginal sections.

Another crop that has been tried with good results is broccoli, with a yield of 10 tons per hectare. This plant is resistant to low temperatures and high salt concentrations, and is, therefore, appropriate for the climate and soils of the region. We will discuss this in the agro-industries section.

Trompillo (prairie berry) is a plant of arid or semiarid zones and grows wild in Durango. It contains a protease useful in making cheese, and its cultivation was tried in the San Jose de Tuitan ejido with good results.

Amarando, or quelite (pigweed), is a plant that produces grain on large stalks. Its nutritive value is important because it contains proteins rich in lysine. This crop will be introduced with advanced techniques this year in "La Brena" region of San Jose de Tuitan.

We must make one thing clear about the cultivation of strawberries and broccoli. We do not intend to replace the basic crops of the region, corn, beans, and wheat, which are indispensable foods for the people. What we do intend is to use only a small percentage of the land which offers the opportunity for occupation by the landless and jobless rural population, especially during times of drought, such as last year. Besides strawberries and broccoli, there are other fruits and vegetables produced in the region, which we foresee as primary material for the agroindustry, that we have projected and which will provide work for a great number of men and women.

Use of Plants in Arid Zones

Within this program, in 1978, a project was begun which proposed, among other things, to utilize prickly pear (an abundant resource in the CIIDIR study area) as an ingredient, together with other available local products, with which to cheaply supplement the diet of cattle.

The huge losses in animal production due to lack of food during the dry season are common knowledge. This is particularly serious in the State of Durango and in much of the northern part of the country and causes the greatest losses in the disadvantaged areas (whose system of production is not very advanced).

This week, in the livestock producing Ejido of San Jose de Tuitan, the third experimental feeding trial was begun with hereford and mixed breed cattle provided by the Ejido. The results to date have been good on the experimental level, and it is now possible to extend the prickly pear-based diet to all the cattle region. The diet has proved efficient and affordable.

A stable with capacity for 70 animals has been established on land provided by the Ejido. The stable was built by the Ejido members from local materials and with advice from CIIDIR personnel. There are also three grinding and chopping machines for grain, various forage plants, and prickly pear, as well as a pilot digester to begin trials for the production of organic fertilizer from animal dung.

This year, it is hoped that the races of cattle in the region will be improved through artificial insemination and other veterinary techniques.

In October of last year, because of the drought that afflicted the State, we presented to the Governor a livestock aid program, using the results and experience obtained in the Tuitan Ejido, with the intention that it be applied to the small ranchers with only a few animals. There is the possibility that we can help, with our direct participation, the organized groups of Ejido members and small farmers with livestock.

Again, we feel that it is not enough to publish and distribute this information through the mass media, no matter how simple it may be, because the farmers and ranchers would probably not understand it. We must work directly with them and have their participation from the start of the project so that they can see how it develops and learn about the problems and achievements as they occur. The rural development programs would yield few practical results if they were carried out exclusively in the laboratories of Mexico City. Experiments done within the confines of four walls would only result in giving prestige to the "researchers."

Integral Health

One of the fundamental activities of this program has been that which relates to community organization, and it has been able to mobilize the populations of Tuitan and Nombre de Dios for participation in the Critical analyses and resolution of community health problems. Neighborhood and sector health committees have been created in almost half of the community of Nombre de Dios, and we hope that all of it will be organized by the end of 1980.

In addition to the above, there are four basic programs:

1. attention to health;
2. school hygiene;
3. infant care; and
4. auxiliary volunteers.

These are carried out according to the guidelines of the SSA and with the participation of the doctors in the service of the School of Advanced Medicine of the IPN and other universities.

Recently, an aid activity has been included in this program which, because of its influence and importance, should be mentioned. This activity deals with teaching preschoolers (3 to 6 years old) by the Montessori system but with adaptations to the needs, interests, and realities of rural children. This is done in the "Casa del Nino" (House of the Child) of the Ejido colony of Vicente Guerrero. The project has encouraged the conscious and positive participation of parents and of the community, in general. The response and results have been very good. The General Delegation of the SEP in the State is now aware of this, and we hope that the system can be extended to other rural communities in the study area and to the entire State. Capable personnel will be trained by CIIDIR.

Apiculture

We initiated an apicultural program in the study area in 1977 with intentions to modernize and promote the production of honey for food and commercial purposes. The honey production per hive was traditionally around 10 kilograms per year; one year after starting our program, production rose to 50 kilograms.

There are now nuclei with varying numbers of hives in Santa Rosa, San Atenogenes, San Jose de Tuitan, Texcalillo, Los Molinos V., Union, and Suchil. The hives and their accessories are being made in Vicente Guerrero in the CIIDIR workshop.

We expect to produce apicultural technicians, through secondary technical schools and from the CECYT's located in the region, as soon as possible, so that they may take responsibility of the hives of their own communities.

The honey produced has been divided among the participating farmers on whose land or orchards the hives are kept. That part of the honey which goes to CIIDIR is sold at very low prices and in controlled quantities to prevent hoarding. This

facilitates its consumption by the greatest number of people, since the objective is that the population enjoys an extra source of calories and minerals.

A floral study of the region has been undertaken to determine the total potential honey production. Once the apicultural technicians are available, the integration of apicultural cooperatives (such as the one in Sucuil, which is composed of professors, students, professionals, Ejidos, and small landowners) will be promoted.

Creation of Agroindustries

The need to produce food and make it available to the public requires organization and industrialization. The agroindustrial development program in the State of Durango, after the preliminary studies, has focused on the elaboration of two projects for two different undertakings:

1. A plant for the integral use of fruits and vegetables through canning; and
2. another plant for the use of these same materials by freezing.

A fruit survey, conducted as part of the preliminary work, indicates that apples, pears, peaches, apricots, membrillos (Quince), pumpkins, and strawberries can be processed. On the vegetable side, we have tried the establishment of crops such as broccoli, and it is expected that cauliflower, cabbage, green beans, and peas can also be attempted.

This is a new and instructing experience as making the land produce is difficult and complex, and to organize that production for industrial processing creates even more problems. To resolve these problems, a group of competent people with experience in crops, industrial processes, and administration of this type of work has been integrated.

The choice and design of processes has been made by the group that works in Michoacan, as well as by CIIDIR. These projects include the production of jams, fruits in syrup, jellies, products with pumpkin and fruit bases, fruit nectars, pickled vegetables, and fruits and vegetables frozen by different processes.

In the organization of the above-mentioned activities, the producers themselves provided most of the investment. In this way, they were assured of receiving their products and the benefits gained from the transformation of the raw materials. The State Government will act as regulator while IPN will provide advice and human resources for administration and technical guidance of the projects. These projects should be functioning by the end of 1981 or the beginning of 1982.

As an additional aid to the research programs of CIIDIR, we expect to have 30 or 40 young people graduate or studying under scholarships in the high schools and centers for Scientific and Technological study of the region. We also hope to reinforce the research personnel of the center. Preference in recruiting will be given to the people of the surrounding communities or from the states of Chihuahua, Coahuila, Zacatecas, and San Luis Potosi.

Higher Research and Education in Natural Resources at the National Polytechnic Institute, Mexico¹

Mario Luis Osoria Victoria²

INTRODUCTION

At the risk of being redundant, it is necessary to point out that the National Polytechnic Institute is the technical and scientific organ of the Mexican State whose origin obeys the postrevolutionary need to form scientific and technological codes to resolve the many problems that our country faced in the 1930's. The National Polytechnic Institute (IPN) since then has represented the most viable option for producing equitable development for the Mexican State and people.

The role (produced by the IPN) that the technicians have played in the national history has, on many occasions, been transcendent. This institution has formed many human resources, all integrated toward the process of productive transformation, which the Mexican society needs with such high priority.

The objective conditions that gave rise to the IPN have varied. However, the basic philosophical postulates of our Institution are still valid for modern conditions and will remain so in the short- and medium-term future. There are still many marked differences and class conflicts which produce notorious inequalities in the distribution of the wealth and services that society generates for each and every one of its members. The work of the IPN has, since its creation, been centered precisely on creating conditions that modify social injustice and place technology at the service of the country.

The themes of study that the IPN follow in the formation of human resources and research now cover almost all disciplines of human knowledge, but are basically confined to those whose orientation is eminently social or those which reality forces us to consider as essential for the independent development of our country. This is the case with the applied study of natural resources in Mexico.

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²Director, Interdisciplinary Center of Investigation for the Integral Development of the Rural Community, Durango Unit. Personal Representative of Dr. Hector Mayagoitia Dominguez, Director General, National Polytechnic Institute, Mexico.

NATURAL RESOURCES

Let us accept, to begin with, that there are those means of subsistence which are obtained directly from nature. For this reason, we must reiterate that their fundamental importance derived from the fact that there are means of subsistence for man, who has the capacity to transform them and adapt them to his benefit. In fact, the history of man could be written as his struggle to control the natural resources, not only by isolated man, but by society, including the kinds of production relationships that have been established by it. It is undeniable that the manner in which the natural resources are used or deteriorated depends upon the character of said relationships.

Nowadays, very few people believe in the deterministic ideas of Drs. Ratzel, Huntington, Haushofer, and others. Explanations are sought in a sociohistoric context and in the form of production that human groups might be capable of developing.

Nature, in short, is not the determining factor; the transforming role of man through technology to a better and more just organization of work and an equitable distribution of wealth generated by these activities, is the determining factor. Man should be the primary objective of the transformations. In synthesis, the exploitation of natural resources should be associated, theoretically and operationally, with the kind of productive system which characterizes the country or region under analysis. When the policy of those who control research and exploitation is to obtain the most profit with the least cost and in the shortest time, activities are concentrated into key areas and are carried out without thought to history. The result is that the reserves are used up, and the physical environment is transformed on the scale and in the manner which interests and is convenient for certain groups, with no account for national or local interests. This is something which all countries should honestly consider.

To adequately face the historic responsibility that the IPN has accepted relative to the study and exploitation of the natural resources of our country, it is indispensable to point out once more that our Institute is oriented by a basically nationalistic spirit which struggles to obtain results applicable to our conditions of social

development. This permits the overcoming of deficiencies without compromising our sovereignty, nor the genuine feeling of independence and identity that all Mexicans have in their souls; with this orientation the IPN develops human resources of a distinct level.

Only since 1977, the number of masters programs increased by eight, four of them with their respective doctorates; one is in ecology, given in the National School of Biological Sciences. The post-graduate population of the school is on the order of 2,948 students, and 492 professors participate in its formation. The above is not only in the area of natural resources, but permits a wider perspective with which to view them.

The relationship between research and instruction is indivisible. Within the IPN, the developments of human resources are included in every research project, on the bachelors level, as well as on the masters or doctorate level. In effect, for every research project carried out in the IPN, human resources are formed and theses or monographs are produced whose value and scientific quality are widely recognized on an international, as well as a national level. The number of research projects to be finished in 1980 is 230, with a budget of 67 million pesos.

RESEARCH IN NATURAL RESOURCES

Practically every school or center of the IPN has at least one research project in the area of natural resources. For example, the National School of Medicine and Homeopathy is studying the biochemical, hematological and neurochemical modifications induced by Datura stramonium in rats.

The School of Advanced Medicine is working with a community Medicine Model in San Pedro Xalpa, D.F., where the influence of social relations and environment on the level of health and disease of the inhabitants of the neighborhood is being studied.

The Center for Interdisciplinary Health Sciences is analyzing the effects of ultraviolet light and photoreactivity in human chromosomes, an interesting study if you consider the conditions of atmospheric pollution in Mexico City.

In the School of Advanced Mechanical and Electrical Engineering, there are proposals to develop a system of reclamation of rain water. If you consider that 85 percent of the national area receives annual precipitation on the order of 300 millimeters, the importance of this study of natural resources is obvious.

The conversion of solar energy to mechanical energy is being studied in the School of Advanced Chemical Engineering and Extractive Industries.

Additionally, the School of Advanced Engineering and Architecture is doing research in the Mixtec

region of Oaxaca (a vast disadvantaged area of the country) to utilize renewable, nonrenewable, and unlimited natural resources to aid the development of the region.

The National Center of Mathematics is aiding a research project called Conjunto, in which mathematical and economic models are used to model the urban growth of Mexico City.

The construction of a solar wood drying kiln is being developed in the Professional Interdisciplinary Unit of Engineering, Social, and Administrative Sciences. It is a project which will permit the more rational use of these natural resources.

Finally, in the National School of Biological Sciences, where a very important number of Research projects are concentrated, the following merit mention: "Biology of the majarra in Aztec Lake, Hidalgo," "Ecological studies of coastal systems," "Damage produced in several species of the Coatzacoalcos River by the pollutants lead and mercury," and others more related to the study and exploitation of the various natural resources. It is important to emphasize the participation of the Department of Nutrition Graduates. They are studying the national use of vegetative and animal resources for the food industry, which is an important aid to the National Food Plan. Besides all this, the studies tend to conserve the ecological relationships of the various resources studied. The work done by this department has frequently been rewarded in national events of high scientific quality.

In late 1979, the Directorate of Research and Technologic Development of the IPN with the Polytechnic community and the collaboration of several researchers, held five seminars to define the research policies. Information was gathered in areas considered to be priorities, which included those of energy, and food and ecology, whose relationship to the theme of this meeting is evident.

DECENTRALIZATION AND INTEGRATION OF RESEARCH AND EDUCATION

The research mentioned above, although related is not completely integrated at this time. The reason is that the IPN, through the Directorate of Research and Technologic Development, has given more cohesion to the lines of investigation that have been ongoing for many years. This policy has been fruitful in the creation of two research centers in the Mexican Province, precisely in the areas where the research is most needed.

The first attempt along these lines took place in the State of Morelos, in a study of the renewable natural resource Cuaguayote (Pileus mexicanus), an abundant fruit in the Yautepec region of Morelos. The importance of this resource lies in its high Mexicana content, a proteolytic enzyme which can be substituted, with many advantages, for papain, widely used in many industries and which has to be imported in large quantities

by Mexico in spite of the fact that the country is a primary producer of it. The research in this field has led to the consolidation of an Experimental Unit of the IPN, which will soon operate with more efficiency and, it is projected, on a national and international level. Another important earlier project that is in the State of Michoacan. The rational use of the soils of this region, such as the introduction of new productive techniques of greater social value, have permitted the creation of a processing industry of agricultural products and, consequently, the optimization of those natural resources. The first was accomplished while conserving the integral participation of the rural population with a technology that does not increase the dependence on the outside on a regional as well as international level.

THE INTERDISCIPLINARY CENTER OF MARINE SCIENCES (CICIMAR)

CICIMAR was founded in September of 1976 in La Paz, Baja California, with the objective of preparing groups of high level researchers specializing in the evaluation and design of fisheries systems (with special attention to marine ecology). With this, the IPN paid a debt and ended the absurdity that in Mexico, a country extraordinarily rich in marine resources, the only State Education Institute lacked a center like the one now operating in La Paz, Baja California.

CICIMAR is structured into five horizontally integrated research and education departments: fisheries, marine biology, oceanology, technologies, and aquaculture. From an educational point of view, there are Bachelor degrees in Fisheries Biology and Aquaculture. Postgraduate studies (Master of Sciences) were begun in 1978, and included specialties in Marine and Fisheries Sciences. Currently, there are 22 students in the first and 14 in the second. Classes are given by 16 specialists in various fields of marine and fisheries sciences, including three UNESCO experts. It is hoped that in 1980 the areas of Fisheries Biology, Marine Ecology, and Aquaculture will be widened.

Of the research projects now being carried out by the IPN through CICIMAR, the following merit attention:

1. evaluation and diagnosis of exploited fisheries resources;
2. evaluation of potential fisheries resources;

These two projects are currently studying such species as sardines, tuna, squid, mictofids, and other renewable resources considered useful to man.

3. a systematic-ecologic inventory of the marine flora and fauna of southern Baja California;
4. morphology of marine species;
5. evaluation of planktonic communities in Magdalena Bay (Bahia Magdalena) south Baja California;
6. an analysis of the variation in abiotic factors in ocean waters and protected waters of southern Baja California;

7. aquaculture: specifically shrimp and mussels; and,
8. industrialization of algae production.

The budget for these eight CICIMAR research projects was 10,204,840 pesos for 1980. It is also worth mentioning that the research being done in this center (which cannot be detailed more here) is an integrated and complete activity with a distinct ideology resulting from an institutional and national policy: decentralization.

THE INTERDISCIPLINARY RESEARCH CENTER FOR INTEGRAL DEVELOPMENT OF THE RURAL COMMUNITY, IPN DURANGO UNIT (CIIDIR)

In October of 1974, a group of IPN researchers initiated a series of studies in the southeast of the State of Durango. The basic goal of this group was to apply and decentralize research with a project called "Introduction of New Crops." In that year, they began a series of actions which, aided by the IPN, the Government of the State of Durango, and CONACYT, grew into the creation, in November of 1979, of CIIDIR in the City of Vincente Guerrero, 85 kilometers from the capital of the state, and with influence over 10,350 square kilometers distributed among five municipalities of the region.

The IPN through CIIDIR, is carrying out research of the highest level which is oriented toward the needs of the population it is intended to serve. The results of this research are turned into real benefits for the inhabitants of the region.

The structure of the Durango unit of CIIDIR-IPN is taken from the Modular System as applied to education and adapted to the needs of the center. There are five perfectly differentiated modules: integral community development, vegetative resources, animal resources, nonrenewable natural resources, and unlimited resources. Each module is subdivided into programs, projects, subprojects, activities, and tasks, and interdisciplinary research is propitiated vertically and horizontally and from module to module.

From an educational point of view, there are currently no formal courses at any level in CIIDIR. These activities are reduced to direct thesis counseling, short courses on specific subjects, and informal education of the community. It is hoped that by the beginning of 1981, a Master's program in Integral Community Health will be initiated in coordination with the school of Advanced Medicine.

Within the lines of research being followed by CIIDIR in the form of programs, projects, or subprojects, the following should be mentioned:

1. use of prickly pear and other arid zone plants;
2. determination of the organoleptic properties of natural jelly and its possible use in

medicine and cosmetology;

3. introduction of new crops;
4. proteolytic enzymes of "Trompillo" for the rural cheese industry;
5. apiculture;
6. study of forest and nonconventional plants as a source of food in rural areas;
7. creation of agroindustries;
8. application of educational systems in the rural environment;
9. qualitative and quantitative determination of the mechanisms of milk fermentation based on microorganism content;
10. census of common plants in the area under CIIDIR influence;
11. entomological study of the area under CIIDIR influence;
12. use of solar energy in productive goods; and,
13. integral health.

The budget for these 13 research projects of the Durango Unit of CIIDIR-IPN was 4,572,857 pesos for 1980.

With reference to the systematic study of natural resources to apply the scientific and technologic gains to the adequate transformation and utilization of the resources, the National Polytechnic Institute has accepted, since its founding, this challenge. Once again, it renews

its willingness to take up, with realism and historic responsibility, the philosophical substance upon which it is based, and rescue it from rhetoric. Our philosophy is to work with a social conscience, a conscience in which the needs of all the Mexicans are those which ask of us as a National Institute, "what to do?" If this transcends all areas of human knowledge, it is fundamental in the field of natural resources. It is never too much to ask ourselves once more, "What kind of planet will our offspring inherit?" It is never too much to point out that the conscious, guided transformation of nature can only be attained when the appropriate methods for making scientific postulates a reality exist, when we have dominated it in a positive way, when adequate techniques are applied to the objective conditions which determine nature, and when (at last) we achieve equilibrium between the goals of the productive forces and the truly national interests in the purest sense of the word.

The IPN can and should collaborate in this task. We are not the ones who should put a value on what we have accomplished up to now, our work could prevent us from being objective. We are sure that we are on the right track and are conscious of our limitations as a nation, as an institution, as a group, as technicians, and as human beings. You here will take with you a very general view of our task. Only time can be the final judge of our actions.

Evaluation of Natural Resources Policy Alternatives¹

G.R. Stairs²

The evaluation of policy alternatives pre-
sumes a well-defined, "reasonable" set of poten-
tial actions from which to make final selection.
It also presupposes that agreed upon object func-
tions can be defined and that acceptable policy
setting methodology exists. Even these simple
requirements are not easily met. For, to look
at alternatives, one must acknowledge the viewers
biases and also the dynamic nature of man and the
biological systems that we will study. Adam
Smith, in "The Theory of Moral Sentiments," wrote:
"The great body of the (discontental)
party...are commonly intoxicated with
the imaginary beauty of this ideal system,
of which they have no experience, but which
has been represented to them in all the most
dazzling colors in which the eloquence of
their leaders could paint it. The leaders
themselves, though they may have meant
nothing but their own aggrandizement,
become, many of them, in time the dupes of
their own sophistry, and are as eager for
this great reformation as the weakest and
foolishest of their followers...."

The man of system...seems to imagine that
he can arrange the different members of a
great society with as much ease as the
hand arranges the different pieces upon
a chess-board; he does not consider that the
pieces upon the chess-board have no principle
of motion besides that which the hand im-
presses upon them; but that, in the great
chess-board of human society, every single
piece has a principle of motion of its
own, altogether different from that which
the legislature might choose to impress
upon it."

Smith's words reinforce the two issues that
deserve our early consideration:

1. the notion that the aficionado's views
may not be shared by all; and
2. the concept that both the dynamics of
man and (in our case) of ecosystems must be
recorded in policy making. We who are enamored
about the need for wise management and preserva-

¹Paper presented at an International Seminar
on SOCIAL AND ENVIRONMENTAL CONSEQUENCES OF
NATURAL RESOURCES POLICIES, WITH SPECIAL EMPHASIS
ON BIOSPHERE RESERVES, held in Durango, Durango,
Mexico, April 8-13, 1980.

²Professor and Director, Center for Resource
and Environmental Policy Research, Duke Univer-
sity, Durham, North Carolina, USA.

tion of ecosystems must recognize that very differ-
ent alternatives may be viewed as acceptable or
desirable by others. While we may, in many
instances, have a majority of the people with us,
it is, nevertheless, important to begin with a
comprehensive evaluation of viewpoints.

Even within the professional groups that will
primarily be involved in agenda setting, there is
variance in selecting alternatives. In early
1971, a group of American ecologists met to de-
fine an agenda for input into the then forthcoming
United Nations Conference on the human environment
(Stockholm, 1972). Their work was divided into
four task groups to study.³

1. biogeochemical cycles of elements essential
to protein production;
2. ecological constraints on man's use of
land, particularly as a result of vegetation-soil
interactions;
3. terrestrial food webs, diversity, and
stability; and
4. man's impact on aquatic systems, parti-
cularly the coastal zone.

They chose to view environmental pollution or
degradation as a derivative of resource develop-
ment and as only one of a number of factors that
influence man. While we could find opportunity
to discuss much of the technical or scientific
information related to our purpose in this meet-
ing under their agenda, I assume that it would not
suffice to satisfy all.

The International Union for the Conservation
of Nature has more recently put forward views on
future needs of mankind vis a vis natural systems.
A study⁴ sponsored by the United Nations Environ-
mental Program (UNEP), together with the World
Wildlife Fund (WWF) provides a contemporary "World
Conservation Strategy" (WCS). The WCS was pre-
pared by the International Union for Conservation
of Nature and Natural Resources (IUCN) in collab-
oration with the Food and Agriculture Organization
of the United Nations (FAO), and the United Nations
Educational Scientific and Cultural Organization
(UNESCO). The WCS is intended to be carried out
by three main groups:

1. government policy makers and their advisors;
2. conservationists and others directly
concerned with living resources; and
3. development practitioners, including devel-
opment agencies, industry and commerce, and trade

³Man in the Living Environment, TIE, Univ.
Wisc. Press, 1972.

⁴World Conservation Strategy, IUCN, UNEP,
WWF, 1980.

unions. From the executive summary of the WCS, the following six points are obtained:

1. The aim of the World Conservation Strategy is to achieve the three main objectives of living resource conservation:

- a. to maintain essential ecological processes and life-support systems
- b. to preserve genetic diversity
- c. to ensure the sustainable utilization of species and ecosystems

2. These objectives must be achieved as a matter of urgency because:

- a. the planet's capacity to support people is being irreversibly reduced in both developing and developed countries
- b. hundreds of millions of rural people in developing countries, including 500 million malnourished and 800 million destitute, are compelled to destroy the resources necessary to free them from starvation and poverty
- c. the energy, financial and other costs of providing goods and services are growing
- d. the resource base of major industries is shrinking.

3. The main obstacles to achieving conservation are:

- a. the belief that living resource conservation is a limited sector, rather than a process that cuts across and must be considered by all sectors
- b. the consequent failure to integrate conservation with development
- c. a development process that is often inflexible and needlessly destructive
- d. the lack of a capacity to conserve
- e. the lack of support for conservation
- f. the failure to deliver conservation-based development where it is most needed

4. The World Conservation Strategy therefore:

- a. defines living resource conservation and explains its objectives
- b. determines the priority requirements for achieving each of the objectives
- c. proposes national and subnational strategies
- d. recommends anticipatory environmental policies, a cross-sectional conservation policy, and a broader system of national accounting
- e. proposes an integrated method of evaluating land and water resources, supplemented by environmental assessments, as a means of improving environmental planning; and outlines a procedure for the rational allocation of land and water uses
- f. recommends reviews of legislation concerning living resources, suggests general principles for organization within government, and in particular proposes ways of improving the organizational

capacities for soil conservation and for the conservation of marine living resources

g. suggests ways of increasing the number of trained personnel and proposes more management-oriented research and research oriented management

- h. recommends greater public participation in planning and decision making concerning living resource use and proposes environmental education programs and campaigns to build support for conservation
- i. suggests ways of helping rural communities to conserve their living resources

5. In addition, the Strategy recommends international action to promote, support, and (where necessary) coordinate national action, emphasizing in particular the need for:

- a. stronger, more comprehensive international conservation law and increased development assistance for living resource conservation
- b. international programs to promote the action necessary to conserve tropical forests and drylands, to protect areas essential for the preservation of genetic resources, and to conserve the global "commons" the open ocean, the atmosphere, and Antarctica
- c. regional strategies to advance the conservation of shared living resources, particularly with respect to international river basins and seas

6. The World Conservation Strategy ends by summarizing the main requirements for sustainable development, indicating conservation priorities for the Third Development Decade.

The WCS is a comprehensive statement that provides one means for comparing alternatives against a set of widely agreed upon objectives. It coordinates well with a concept of dynamic or "working" conservation, thus, avoids overfocus on reserves or preserves without losing sight of their importance. Nevertheless, as the authors acknowledge in their "Preamble and Guide," "(it) inevitably reflects a compromise among conservationists---and between conservationists and practitioners of development. An important feature of the WCS is the plan to publish a paperback version for the general reader thus making public awareness a feature of this important effort. For the professional, there are plans to publish a source book, in a number of volumes, over a period of several years.

These examples provide a sampling from a larger set of agendas that coexist (with some agreement and some disparity). A further measure of heterogeneity can be added by examining the mythology of "conventional wisdom." For example, it is often assumed that developing countries have predominately unspoiled, virgin territory and, thus, have less need for national parks and preserves. In the developed countries, with advanced agricultural and resource technology it is often assumed that matters of soil and resource conservation are totally resolved and that losses to ero-

sion are minimal or nonexistent. Similarly, one may hear that "developing countries do not have an interest in environmental pollution or resource preservation, since their need is more immediate and related to economic development." These, and other false statements, remind us that the world cannot be treated in generalities or as an undifferentiated whole; there must be geographic reference and specificity in choosing resource policy alternatives.

Even generally agreed upon alternatives may provide disparate results when implemented in different ecosystems. For example, the influence from environmental concern about DDT moved rapidly around the world in the 1960's. In Sri Lanka, the government banned DDT, only to see the number of deaths from malaria increase from nearly zero in 1961 to more than 10,000 in 1968. Such irony can result from blindly choosing alternatives that are effective or desirable in one area, but that may not be so in another. In the Sri Lanka example, there was a clear need for substitution to maintain the malaria control program as DDT was phased out.

Development usually provides both opportunity and need to increase effective natural resource policy setting. It is interesting to consider that in many regions, an improvement in the environment can only come from development or other exogenous input. Miguel Ozario de Almeida of Brazil has said⁵ "...given appropriate space and time the environment will be able to cope with foreign matter injected into it; and they (economic and environmental problems) tend to diminish with economic development itself, contrary to the prevailing conditions in developed countries. In fact, it is impossible to correct this process of pollution without development, in part because one of the very definitions of development consists in not having this type of pollution, and in part because the resources necessary to cope with it are not available to low levels of income." An analogy to land use policy could call for alternatives that insist upon the maintenance and improvement of reserve or reserve areas as a condition for development and improvement of the managed ecosystems or agriculture, grazing, or forestry. Such a linkage would require definition of the desired balance for land use in a comprehensive manner and could attach financial support for reserves as a condition to total land use development.

The question of agenda setting could, of course, be extended to much more specific items. The discussion of such items I will leave to the sector papers presented at this meeting and to our audience interaction. Rather than relate to specific alternatives in a given region, I feel more obligated to focus our attention on the methodology of policy setting and, in particular, upon the politics of planning and quantification techniques. To do so with some confidence that a policy-making methodology, to which no one pays attention, is not what we need. Nor do we wish to establish adversary

relations between various planning technocrats at natural resource or other sector levels. We may also note that policy making will range from an ad hoc process, decentralized at local levels to more comprehensive, central planning systems. While seemingly self-evident, it is, nonetheless, important that resource-policy methodology pay formal attention to local decentralized inputs. Alternatives can only be normalized for appropriate ecosystem responses at the decentralized level. Conversely, it is a mistake to attempt a policy definition at local levels that cannot be related to national or regional state planning and policy. Thus one might suggest that contemporary policy making requires a dialogue at all levels by "all concerned parties." In so doing, the original alternatives slate may be kept intact, added to, or modified for final agenda shaping. After all public and private inputs are received, final selection and evaluation of alternatives is more easily accomplished.

The dynamics of policy methodology places heavy emphasis upon knowledge and information systems, and must also recognize the limitations therein. It is important to select policy alternatives that address the need for continued inputs from research and information systems. The type of information we seek will allow a view of trade-offs involved in selecting various alternatives. To efficiently utilize the information, we require a methodology that will assure a comprehensive systems approach. The availability of contemporary, computer based systems analysis methods suggests these as useful to our purpose. An example of simulation techniques is presented elsewhere in the program by Rasmussen and Ffolliott; in this paper, I will only comment briefly on policy related to the technique. The advantages of simulation are obvious and, dependent upon the technique, provide a useful means for quantification of symbolic logic and for assuring that data are scale-compatible. The further advantage of rapidly estimating optimality over a range of alternatives is clear. However, the acceptance, both initially and finally, for such techniques will continue to rest upon verification. The development of time-series data should be a constant part of systems analysis policy.

Information retrieval technology has developed at a rapid pace during the past decade. Progress has been made in terms of information input and in the format and manipulation ability of advanced computer graphics. Advanced techniques of remote sensing join satellite imagery with conventional aerial photography and ground truth to provide new accuracy in resources assessment. Simulation techniques can be used to further relate observed data to complex and dynamic systems, and to, thus, enhance the efficiency of alternatives evaluation.

In summary, I have suggested that evaluation of resource policy alternatives may begin by developing accurate data bases and, then, quantitatively evaluating the data through systems and simulation models as a necessary prelude to the policy phase. It is at the interface between quantification and more integrated socioeconomic decisions that major

⁵Development Digest, II; April 1972; p.23.

opportunity is provided to define policy alternatives for presentation to the public and their elected officials. Maintaining a view of resource policy agendas (put forth on a global basis or in other nations) can also be of great help. Comparison between local or national goals and those sought by others in a similar situation helps to assure efficiency and state-of-art decision making.

The setting of policy alternatives is a formidable task indeed, but one that must be pursued with great vigor, if we are to succeed in meeting our professional objectives. To that end, I suggest that sharing technology and methodology for selecting alternative policies can be of most immediate value. In so doing, we need not forego the traditional sharing of

scientific information related to biological, physical, or ecological systems. It is, however, important to recognize that choosing effective policy alternatives requires aggregation into well-defined systems analysis and that new approaches and techniques are under dynamic development. Once we have assumed that the task is as complete as possible at the natural resource level, we can begin the work of relating to cultural, social, and behavioral aspects. Only then, can we assume that our professional efforts have been placed into compliance with Adam Smith's suggestion that "in the great chess-board of human society, every single piece has a principle motion of its own, altogether different from that which the legislature might choose to impress upon it."

Simulation of Consequences of Implementing Alternative Natural Resources Policies¹

William O. Rasmussen and Peter F. Ffolliott²

INTRODUCTION

Simulation techniques are often used to reproduce the behavior of biophysical systems in the form of a model that closely represents real life. Through simulation, appropriate models can be operated to obtain alternative solutions to land management problems. Simulation techniques do not necessarily generate optimal solutions; rather, they show alternative results that allow an investigator to make the best decisions for a given purpose. Commonly, simulation exercises are carried out on digital computers, since these exercises usually require many calculations. However, simpler simulation exercises can be executed without computers.

Through the application of computerized simulation techniques, it is possible to analyze consequences of implementing alternative natural resources policies, and then select the best course of action from these alternatives. In essence, alternative policies are translated into land management scenarios; these scenarios are then structured into simulation exercises. By obtaining solutions to the simulation exercises and comparing the respective outputs with social and environmental acceptance criteria, natural resources policies that meet desired land management goals may be recognized.

Many computerized simulation techniques are currently available to analyze the impacts of land and management practices on an ecosystem. In particular, a group of interactive computer simulation models has been developed to aid natural resources policy makers estimate consequences of implementing alternative policies. This group includes modules that address the following topics: growth and yield of forest overstories; production of herbaceous understories; animal carrying capacities; and wildlife habitat assessments. Briefly, these modules are described herein, and an example of their use in analyzing alternative policies is presented.

GROWTH AND YIELD OF FOREST OVERSTORIES

Simulators designed to estimate the growth and yield of forest overstories fall into two categories: models that are broadly structured to represent a variety of tree species and models that are specifically structured to represent a particular tree species.

An example of a computerized simulation technique in the first category is called STAND. By design, STAND is structured to estimate the growth and yield of forest stands comprised of a single tree species or a mixture of tree species, through stand projection methods applicable to uneven-aged forest stands.

The simulation objective of STAND is to predict the growth (both gross and net) and yield of forest stands prior to and, if appropriate, following the implementation of various land management practices. Inputs to this modular component include a listing of trees per hectare by size class, and associated diameter growth rates and volume expressions. As management is prescribed to change these inputs, posttreatment growth and yield are interactively generated. Silvicultural management practices that can be simulated within STAND represent an array of viable options for the different forest stand compositions being considered.

Outputs derived from STAND, including summaries of basal area levels through time prior to and following a management redirection, are readily used by other modular components. As the manipulation of forest overstories is a primary management activity affecting many aspects of an ecosystem, such interfaces among modular components are critical to realistic simulation of an ecosystem's overall behavior.

PRODUCTION OF HERBACEOUS UNDERSTORIES

A computer simulator has been structured to estimate herbage (all understory species) production from knowledge of forest overstory parameters, precipitation amount, and if appropriate, time since the implementation of a land management practice. Depending upon the particular simulation objective, a user may operate this component, called UNDER, individually or in conjunction with another model. In the latter instance, outputs from other modular components in the group are utilized as inputs.

¹Paper presented at an International Seminar on SOCIAL AND ENVIRONMENTAL CONSEQUENCES OF NATURAL RESOURCES POLICIES, WITH SPECIAL EMPHASIS ON BIOSPHERE RESERVES, held in Durango, Durango, Mexico, April 8-13, 1980.

²Assistant Research Professor and Professor, School of Renewable Natural Resources, University of Arizona, Tucson, Arizona, USA.

Many of the previous attempts at developing computer simulation techniques to estimate herbage production have been dependent, primarily, on input variables depicting forest density conditions. While this approach remains viable and has been utilized in UNDER, the herbage production simulator also utilizes knowledge of forest overstory growth. Estimates of herbage production that are based on knowledge of this variable appear consistently of higher precision than those based on knowledge of forest density alone.

UNDER partitions simulated herbage production into three categories: grasses and grasslike plants, forbs and half-shrubs, and shrubs.

ANIMAL CARRYING CAPACITIES

In the modular component structured to predict animal carrying capacity, referred to as CARRY, herbage production (entered as a direct input by the user or obtained from the herbage production simulator) is partitioned into usable forage for domestic livestock or wildlife species. Appropriate plant species to include in each forage component were ascertained from existing literature relevant to the preferred foods for these animals, along with information about appropriate or proper utilization percentages. The amount of usable forage required per animal unit month (AUM) for the animal species being considered is input directly by the user.

It has been assumed that the proper use factors to be applied in CARRY will be introduced by the user in an attempt to meet specific management objectives. It may be necessary, for example, to reduce a proper use factor on a particular range that has been subjected to prolonged overgrazing pressures. As baseline information relating to proper use factors increases, the ability to predict carrying capacities will improve accordingly.

With respect to the number of months that domestic livestock and wildlife species will actually be consuming forage on any tract of rangeland, this value is quite variable depending, in part, upon weather factors (time of snowfall in the autumn, time of snowpack disappearance in the spring, etc.). At best, only estimates based on local knowledge of average situations in the long run can be made. However, to provide a point-of-departure in utilizing CARRY, specific forage consumption time durations have been selected. It should be emphasized that the user can readily override these default duration values to more accurately reflect local conditions, if better information is available.

At this time, relatively little can be said about possible constraints that may affect the distribution of animals that are considered by CARRY. While it is known that various factors may restrict (or at least modify) animal movement, explicit identification and subsequent quantifi-

cation are currently difficult. Conceivably, portions of a tract may be eliminated from use because of movement constraints (physiography, fences, etc.), which may necessitate appropriate reductions in animal stocking rates.

WILDLIFE HABITAT ASSESSMENTS

Simulators that assess habitat quality fall into two categories: models broadly structured to represent a variety of animal species (including game, nongame, and domestic) and models specifically structured to represent a particular animal species.

An example of a modular component in the first category is HABRAN (HABitat RANking). In essence, this component synthesizes ranked response predictions which, in turn, can be summarized and arrayed as pattern recognition models. Within HABRAN, animal habitats are assigned numerical values ranging from 0 to 10, with habitat quality in an ecosystem increasing with numerical value. The specific assignment of these values is achieved through analyses of functions that relate habitat preference to readily available inventory-prediction parameters, the magnitude of which are altered by alternative land management practices. By comparing numerical habitat quality values for existing conditions with those predicted for habitats modified by management redirection, either an increase (+), a decrease (-), or no change (0) is determined. Then, a matrix of pluses, minuses and zeroes arrayed for all animal habitats and management alternatives of interest (by definition a pattern recognition model) can be displayed to provide insight into comparative management impact.

The HABRAN component is, in a sense, a first-level-of-interest assessment of the impacts of alternative land management practices. In many instances, this sort of analysis may be all that is required. However, if estimates of carrying capacities and animal distributions are needed, other modular components may be called into play.

EXAMPLE OF SIMULATION

Perhaps the best way to illustrate the use of simulation techniques to analyze consequences of implementing alternative natural resources policies is through an example. For illustration, four policies will be considered for possible implementation in a montane forest ecosystem on a biosphere reserve, and the best course of action will be selected from these alternatives. While all of the policies under consideration stress enhancement or (as a minimum) maintenance of natural resource production, different resource products are emphasized.

One policy states that existing carrying capacity for domestic livestock (in specific, for cattle) will be increased, while maintaining (or enhancing) forest growth and yield and wildlife habitat quality (in this example, deer habitat).

to policies require an increase in growth and yield of forest overstories by encouraging (in one case) an uneven-aged forest structure of (in the other case) an even-aged forest structure. A part of these policies, maintenance (or enhancement) of carrying capacity for cattle and deer habitat quality will also be required. The final policy under consideration is to retain the current land management system, that is, to allow things to remain as they are.

By adopting a policy to increase existing carrying capacity for cattle, forest overstories on moist sites (one third of the area, adjacent to drainage) will be converted to grass. Through silvicultural treatments, forest growth and yield on residual sites should be increased, attempting to maintain growth and yield overall. Conversion of moist sites to grass should enhance deer habitat quality by increasing food and improving habitat diversity.

Intensified silviculture will be prescribed to increase growth and yield of forest overstories, a requirement in two of the policies. A group selection treatment (involving a reduction of 25 percent in forest density) will be followed if an even-aged forest structure is the policy. Under a policy of even-aged forest structure, a shelterwood treatment (in which the forest is gradually removed in a series of partial harvestings) will be imposed. Carrying capacity for cattle should be increased in both cases, as a reduction in forest density usually increases grass production. Deer habitat quality should be enhanced under both policies.

Current land management is assumed to be a form of group selection, but less intensive than would be required under a policy of an uneven-aged forest structure. With this management, production levels for all natural resources remain unchanged. However, as costs of implementing a new policy would not be incurred, benefit-cost relationships may be more attractive than investing in a management redirection. From a simulation viewpoint, it is important to include the current situation in a simulation of consequences to furnish a basis for analyzing possible change.

Using the group of interactive computer simulation models described above to estimate consequences of implementing the hypothetical policies, the following output was obtained:

Item	T ₀	T ₁	T ₂	T ₃
	As is	Convert	Uneven-aged	Even-aged
Forest growth (cu. m/hectare)	4.2	2.5	5.5	5.2
Forest yield (cu. m/hectare)	4.4	3.9	4.9	3.8
Carrying capacity (cattle) (animal units)	13.2	27.4	17.2	19.3
Wildlife habitat (deer) quality value)	6.7	+	0	+

At this point, a decision must be made as to the best course of action in selecting a policy for implementation. While other social and environmental consequences not included in this example (impacts on other natural resources, costs of implementation, etc.) should be examined in the decision process, for purposes of illustration, only those consequences estimated above will be considered.

With respect to a conversion policy, T₁, carrying capacity for cattle is predicted to double, and deer habitat should be enhanced. However, the silvicultural treatments to be imposed on residual sites will apparently not maintain forest growth and yield overall. Therefore, a decision not to implement this policy seems appropriate.

The policies of increasing forest growth and yield through intensified silviculture are predicted to meet acceptance criteria regarding these parameters. A policy of uneven-aged forest structure, T₂, should provide a higher level of forest growth and yield than a policy of even-aged forest structure, T₃. However, carrying capacity for cattle is predicted to be greater under an even-aged forest structure, and deer habitat quality should also be enhanced with the latter policy. Therefore, a trade-off analysis may have to be made to determine which, if either, of these policies should be implemented. While simulation techniques (such as those employed in this example) may furnish input to a trade-off analysis, decisions as to policy implementation are also based, in large part, on professional judgements constrained by inherent natural resources productivity and long-term utilization goals relative to these resources.

A decision to retain the current land management system, T₀, is certainly a valid option. Such a choice may be made if, for example, costs incurred to implement any of the other policies are excessive.

In the final analysis, while additional information may be required to select the best policy for implementation, computerized simulation techniques may be useful in analyzing consequences of implementing the alternative policies under consideration. However, these simulation techniques will not necessarily generate optimal solutions. Instead, through simulation, impacts of alternative courses of action may be predicted and provide input to making a decision regarding policy implementation.

Land Use Planning in the United States¹

M. Rupert Cutler²

It is not often necessary to allocate many individual tracts of land to the extremes of either complete preservation or intensive development. Biosphere Reserves and wilderness areas are essential and valuable to science and to society at large. I make this point in my paper, "Wilderness Decisions: Values and Challenges to Science," which appeared in the February 1980 issue of the Journal of Forestry; but, I would like to emphasize the point that the majority of the world's landscape, not so preserved, can be managed so that the environment is protected, public opinion regarding management objectives is respected, and the food, fiber, forage, and forest products required by society are produced from the land economically.

In the United States, one third of the land is administered by public agencies such as the Forest Service of the Department of Agriculture and the Bureau of Land Management and the National Park Service of the Department of the Interior. Two thirds of the land in the United States is owned by private individuals and corporations. Most of this private land is divided into relatively small, family-owned and operated farms and ranches. Our farmers and ranchers like to describe themselves as free private enterprise capitalists, but they are constrained, as well as assisted, by government in many ways; we do not have an unconstrained laissez faire system today, although one did exist in our country in the 19th Century.

In the next few minutes, I will summarize the institutional mechanisms available to policymakers in the United States to influence land and resource use on both public and private lands in our country.

This review of what is in place in the United States today (i.e., the means now available to us to improve land use and, thereby, improve our people's quality of life) may complement yesterday's presentations which emphasized more ideal processes which involve the use of data, computer models and public consensus that have not yet been perfected.

¹Paper presented at an International Seminar on SOCIAL AND ENVIRONMENTAL CONSEQUENCES OF NATURAL RESOURCES POLICIES, WITH SPECIAL EMPHASIS ON BIOSPHERE RESERVES, held in Durango, Durango, Mexico, April 8-13, 1980.

²Assistant Secretary, United States Department of Agriculture, Washington, D.C., USA.

All public land in the United States is undergoing a new round of comprehensive land and resource management planning. The key Federal statutes requiring the preparation of these management plans are:

1. the Forest and Rangeland Renewable Resources Planning Act of 1976 and
2. the Federal Land Planning and Management Act of 1976.

These laws require adoption of new, multiresource plans for every one of our 154 National Forests by the year 1985, and require that a similar process be carried out on the public rangeland administered by the Bureau of Land Management.

How this planning is done is directed, in part, by other statutes, including:

1. the Wilderness Act;
2. the National Environmental Policy Act;
3. the Freedom of Information Act.

These laws provide direction to protect wilderness values, where they still exist, consider an array of practical alternative plans and their impacts on the environment, and expose these alternatives to public review and comment prior to adoption of any one of them. Administrative appeals and judicial review are provided for also.

The most important aspect of this new public land planning process, covering some 350 million hectares of land, is the use of interdisciplinary planning teams, which include biologists, sociologists, economists, and landscape architects. Such teams are being used on each National Forest and Bureau of Land Management district, to assure that fish and wildlife habitats, archeological values, aesthetics, water quality, recreational opportunities, and local economic impacts are considered, while sustainable production of raw materials needed by society is provided for, to the extent such production is compatible with the protection of long-term productivity.

Truly, multiple-use management of the public lands in the United States has come of age; it is no longer a "cover" for timber management or an overemphasis on grazing, but is an increasingly sophisticated process providing something for all users, urban and rural, where possible, taking advantage of opportunities to produce and conserve simultaneously. This is not to say that all plans being produced today are excellent plans, but the current process is a vast improvement over its predecessors.

On the 700 million hectares of private land in the United States, landowners choose their own objectives and pursue the profitable production

of food crops, livestock, timber, and other commodities, while behaving as good neighbors from the standpoint of the environmental impact of their activities. They must behave reasonably well, because their neighbors can sue them in court if they create a nuisance, and Federal laws administered by the States require the maintenance of air and water quality standards.

Millions of land-owning farmers and ranchers in the United States have detailed conservation plans for their lands, prepared for them (free of charge) by local technicians, called district conservationists, employed by the Soil Conservation Service of the Department of Agriculture. The cost of installing the soil and water conservation practices, wildlife habitat improvement, and woodlot management techniques prescribed in the conservation plan is shared with the landowner by the Department's Agricultural Stabilization and Conservation Service; the Federal government pays half the cost of approved practices. The Cooperative Extension Service at each State landgrant university sends results of agronomic and forestry research to the farmers to teach them how to produce profitable crops while protecting the environment. The Farmers Home Administration of our Department loans money to farmers at subsidized low interest rates to help them make the necessary capital investments to get started in farming and to recover from emergencies. Price supports are established to guarantee a minimum price on certain crops.

Thus, our government assists our farmers, ranchers, and woodlot owners in many ways to assure their well-being. This, in turn, helps assure both production and conservation. Currently, our government is giving renewed attention to soil and water conservation policies and practices on private land. The Soil and Water Resources Conservation Act of 1977 directed the United States Department of Agriculture to assess the condition of our nation's soil and water resources, to document the need for conservation practices, and to devise appropriate strategies to implement these practices. Under the leadership of the Soil Conservation

Service, this appraisal and policy development process requires extensive public participation and will culminate in major recommendations to the President and the Congress. The result of all this decentralized, mainly voluntary action, at the local level under uniform federal guidelines, is that much of our United States landscape already has been planned from a conservation standpoint, and is being operated both to provide the products and services which society needs from the land, for food, clothing and shelter, and to protect the environment.

In summary, a nation does not need to wait until it has an ideal national plan to make important progress toward sound resource management and conservation goals.

Obviously, each country has its own tradition within which its citizens must work, the answer as to the best process will differ from country to country.

But in every country, there are knowledgeable persons in local areas (farmers, businessmen, teachers, university and government scientists, and private and public decisionmakers) who can proceed to develop appropriate local conservation and rural development recommendations and perhaps assume local support for implementation of plans.

I urge you to become catalysts, to encourage people to address this subject, and to give local planners your confidence, support, and economic incentives where you can, so that some incremental progress can be made immediately, rather than waiting for the perfect process, which will produce the perfect plan.

Perhaps we are wrong in the United States for "shying away" from "national planning." It may come someday, but our people will not accept it now. However, much good work is being accomplished under that title on the decentralized basis I have described, and we are trying to improve the process as we use it.

The Real World of Policy Making and Decisions¹

Robert L. Herbst²

Since this seminar is an exchange of communications between scientists and policy makers, and since the papers presented have been directed at facts, scientists should know concerns policy makers have, and what policies should be. Those of us at a policy level should share the "real world of policy making and decisions" with you. This is what I intend to do. While the system may be different in your country, the responsibilities and problems are similar.

In the United States, broad national policy is considered and determined at three levels of the Federal government. The Legislative branch establishes broad policy by legislation in response to societal interests; the Executive branch carries out and administers policy, and has authority to make additional policy within the framework established by Congress; and the Judicial branch examines the legality of policy, and enforces it.

As a representative of the President and Executive Branch, I am the administrator of three large Federal bureaus--National Park Service, Fish and Wildlife Service, and Heritage Conservation and Recreation Service. Let me describe my personal decision-making environment as an example. I was selected for the position by the President and by the Senate, therefore, it is a political appointment, but since the title was created by statute to include "Fish and Wildlife" it presumes a qualification by education and experience. I have background experience of 27 years, which includes education as a wildlife manager and forester, teaching, public relations, and an administrator of 17 years.

Let me briefly explain my job. I administer over 80 million acres of national parks, parkways, historic sites, monuments, and cultural centers; 83 million acres of wildlife refuges; 97 fish hatcheries; schools, training and research centers, wild and scenic rivers, and trails of all types. Programs include fishery management, wildlife management, historic preservation, outdoor recreation, a number of grant programs, archaeology, endangered species of flora and fauna, ecological and biological research, regulatory authority over adverse effects to the environment, and so forth.

¹Paper presented at an International Seminar on SOCIAL AND ENVIRONMENTAL CONSEQUENCES OF NATURAL RESOURCES POLICIES, WITH SPECIAL EMPHASIS ON BIOSPHERE RESERVES, held in Durango, Durango, Mexico, April 8-13, 1980.

²Assistant Secretary, United States Department of the Interior, Washington, D.C., USA.

My three agencies include as many as 35,000 employees, a budget of as much as \$2.8 billion a year, and enumerable buildings, planes, cars, trucks, and other types of equipment.

I also chair or serve on approximately 10 Presidential Commissions, including Vice Chairman of the Great Lakes Fishery Commission, United States Commission to UNESCO, member of the President's Interagency Council, and Chairman of the Migratory Bird Commission. From this brief description you can get a feel for the magnitude and diversity of responsibility. As an administrator, the job includes supervision of the three agencies; personnel management and selection; budgeting; legislative efforts; education and informing; communication; issue resolution; management improvements; decisions of all types; the development of new programs; selling to Congress and the public the President's ideas on programs and the related finance and manpower needs; and international negotiations and administration of approximately 40 multilateral and bilateral treaties.

The role of an administrator is a complex and busy one that requires scientific facts, philosophical ideas, legal advice, economic information, and public opinion and involvement in order to make a decision. The most difficult and frustrating need of an administrator is time. Therefore, he must have complete confidence in his staff and outside information, because decision making on issues covers a short time span.

When I must make a decision on an issue, I direct my staff to quickly outline the issue, document it, give me the alternatives for solving it--the pros and cons of each alternative--recommendations and why; then a decision is made, and we go on to the next issue.

I can make no decision without the scientist (I can, but there would be many mistakes if I did). It is important that I have the scientific facts. And the scientist needs the decision maker or his work results in no action. We both need society's support or we both don't exist. But more important, the care and condition of our natural resources would decline rapidly, as would the quality of life.

Simply stated, an administrator must do three things:

1. plan;
2. do; and
3. evaluate - the same three things in all of life.

Public policy is referred to by some as the "art of the impossible," but really it is a changing, dynamic, posture at any given time. It is not made in reality by one person but by the public at large. The role of the decision maker is to face the diverse pressure of facts, law, and opinion, make a decision, and carry it out. In my department we weigh development and protection equally, but if an impasse occurs we decide on the side of conservation. Why? Because it is easier to redo a decision than undue a failure.

What we need from the scientist are reliable facts; timely, precise responses to requests for information; the separation of hard data from opinion; clear recommendations we don't have to hunt for; and an understanding attitude when decisions don't exactly fit his input and advice.

You need from us clear instructions when requested; the hypotheses involved as we see them for starters; discussion of priorities; and use of effort. We are all scientists, philosophers, and decision makers to varying extents; we are

all a part of society as a whole. We must work cooperatively because we are in the boat together in the waters of life. We sink or swim together as does the future of mankind.

My philosophy has been these words: Your Creator has created all things necessary to sustain you and found them to be good. While you dwell among the mortals you may partake. Use them wisely and judiciously. Guard them closely, squander them not. For if you are untrue to this sacred trust, mankind shall not be perpetuated, but shall perish from this Earth.

In conclusion, the role of the administrator is a lonely one, a tense one, a frantic one, and one in which you lose friends with every decision. But, it is an extremely gratifying challenge to serve mankind.

Abraham Lincoln said it well when he said, "If when my time comes to lay down the reins of power I shall have lost every friend on earth save one - the one deep down inside of me - I will then have done my job well."

Nature Reserves and Conservation in Central America¹

Jaime Incer²

The isthmus occupied by Panama and Central America serves, we all know, as a bridge or transition zone between the flora and fauna of North and South America. This transition can be seen throughout the length of the isthmus, as well as in its altitudinal zones. The area also contains several endemic species which evolved in specific local environments; these are residual populations with paleoecological ancestors and are confined by geographical barriers, altitudinal isolation, etc. (fig. 1).

The high biologic potential of Central America is exhibited in the humid montane, premontane, and tropical forests along the Caribbean slope, where the humid eastern winds blow from sea level up through the ecological zones to the highest peaks of the central mountains, which form the backbone of the isthmus.

The importance of these life zones lies not only in their species diversity, but also in their wide areal extent, especially those that cover the wide plains of humid Caribbean slope.

However, all of the Central American countries except El Salvador which does not have a Caribbean slope, are suffering from a rapid migration of the population from the Pacific regions to the Caribbean. The continuing colonization of this region is slowly reducing the natural vegetation to an alarming extent (fig. 2). To give an example, it was estimated thirty years ago that 60 percent of the Nicaraguan land (mostly situated along the Caribbean slope) was covered by tropical rain forests. Today, this has been reduced to a little less than half.

Some of the causes for this gradual reduction of the tropical rain forests in Central America are as follows:

1. the expansion of agricultural lands toward the Caribbean Sea through spontaneous colonization. Since this takes place in an irregular and uncontrolled manner, large virgin tracts of tropical

forests are sacrificed through slash and burn agriculture.

2. precarism or the illegal possession and use of isolated and remote lands under state control. The precarists clearcut forests without even making use of its resources. Once the wood is burned and the land cleared, the land is sold to people with agricultural interests.



Figure 1.--Sumu Indian hunting "kakumukas" (iguana) along rain forest river banks in Nicaragua.

¹Paper presented at an International Seminar on SOCIAL AND ENVIRONMENTAL CONSEQUENCES OF NATURAL RESOURCES POLICIES, WITH SPECIAL EMPHASIS ON BIOSPHERE RESERVES, held in Durango, Durango, Mexico, April 8-13, 1980.

²Director, Center for Scientific Investigation, Central Bank of Nicaragua, Managua, Nicaragua.



Figure 2.--Rain forest along Waspuk River in north-central Nicaragua.

3. authorized colonization by entire families, generally forced from the marginally productive Pacific lands to the humid Caribbean slope where, once settled, they cut the forests and start subsistence farms, hoping for a limited, but ephemeral yield. After a few years, production falls due to depletion and erosion of the soil, forcing the farmers to open new lands, progressively destroying more virgin soil. This type of colonization is generally the result of a national development policy based on agriculture and instigated by the use of so-called "roots of penetration into the forest," under the pretext of increasing agricultural production and stimulating regional economic development. This policy does not take into account the ecological role played by the tropical soils, or is not conscious of the fact that it is contrary to any sustained agricultural development in regions whose lateritic soils have been depleted of their soluble minerals by the frequent rains, which exceed two meters a year.

4. logging, which contributes to the humid tropical forests. This exploitation throughout all of Central America is based primarily on short-term profit, without providing integrated management and recuperation programs for those broad-leafed hardwood forests.

Roads cut into the forest by logging companies are later invaded by precarists and slash and burn farmers who further contribute to the irreversible destruction of the forest. The natural ecological succession of the forest is, thus, ended through years of cutting and burning for the purpose of obtaining new lands of little agricultural value and more extensive range lands.

In this way, we can explain how the vast pristine broad-leafed hardwood forests (which

covered extensive areas of the Caribbean slope of Central America) have been irreversibly disappearing, now reduced to isolated disconnected patches. Even in the largest countries of the area, Guatemala, Honduras, and Nicaragua, there are no longer intact areas larger than 10,000 square kilometers which can be managed as true representative natural reserves of humid tropical forests. Even within the reserves that exist, especially along the deep rivers that penetrate them, there are already settlements taking advantage of the alluvial soils to plant plantain, corn, beans, and other subsistence crops. That romantic vision of ancient wild trees whose branches form literal tunnels along the rivers is, every day, more a thing of the past.

I believe that, on a public level, there is now some understanding of the problem, in spite of the fact that there still are some planners who consider the tropical forests an obstacle to development instead of an aid. That concept of development which implements agricultural cultivation of forest lands, accompanied by agricultural colonization of the Caribbean slope, forms part of the economic programs of all of these countries. Ecological considerations do not carry enough weight to be taken into account. It would be advantageous, in light of these facts, to delimitate as a preventive measure, some of the representative areas of natural tropical wet forests, montane and premontane, as large natural reserves or Biosphere Reserves. The establishment of watershed management programs for hydroelectric power could be a convincing argument in those mountainous countries with energy problems.

The ecological impact of those works would be less than those of future agricultural or logging ventures.

Also, I believe that we cannot wait for these countries to gain an adequate level of ecological consciousness before trying to solve these problems of development. I think that, as ecologists, our arguments may seem a little academic. We need to find tangible economic arguments to demonstrate the advantages of conservation of the tropical rain forests of Central America. We hope that the congresses and seminars on this subject will adopt reasonable recommendations or resolutions to submit to the governments of these countries, and that not only conservationists and ecologists participate in those reunions, but those who plan and direct the territorial development programs as well. We also hope that the international development agencies take note of these arguments and adjust their economic and technical aid accordingly to achieve a higher ecological consciousness in the policies of these impulsive countries, without forgetting that, in this narrow Central American isthmus, there are now 18 million inhabitants in search of new horizons and frontiers.

Management of a Tropical Forest¹

Frank H. Wadsworth²

We have been discussing Biosphere Reserves as if their only objectives were the preservation of germplasm, ecological research, and education. An equally important objective listed by MAB is the conservation of diversity. This does not mean only in the ecological sense. It involves the integration and management together of diverse land uses. This process of management is, of itself, complex and vital to the accomplishment of the other objectives that concern us.

A Biosphere Reserve, not entirely unlike La Michilia in Durango, the Luquillo Experimental Forest in Puerto Rico, is under management for diverse purposes. The total area, some 11,200 ha, is altogether forested, but only 55 percent of it is primary. Of the primary forest, some 92 percent is designated to continue to remain unmodified. About a quarter of this is reserved in two research natural areas, to be used only for non destructive investigations: within these two areas are 4 life zones, 4 ecosystems, 60 endemic species of trees, two endemic amphibians, and one endemic bird.

Another third of the primary forest is designated for wilderness, and for recreational use. Neither of these uses is to be permitted to modify any significant forest area. Another third is reserved for watershed protection.

Recreational development, supporting about 1,500,000 annual visits, includes roads, trails, observation towers, and picnic areas. A 7-day-a-week visitor information service serves a continuous flow of school students, as well as tourists and other visitors.

Research and demonstration of timber production is in progress on 25 percent of the reserve, nearly all of it is secondary forest. About 30 percent of the area is subject to improvement of the native forest, the rest being enriched by underplanting. Both research and demonstration are conducted on this area.

The forest as a whole is a source of local pride. There is no pressure to stop or modify

the management program.

Dr. Halffter's questions, asked earlier in the seminar, presented philosophically to us to arouse our thinking, seem worthy of comment. One concerned with what he referred to as an "ambiguous land ownership pattern" in parts of Mexico, appears to present no insurmountable problem in resource protection and conservation elsewhere. Certainly there must be ejidos receptive to well presented technical counsel.

A second question raised by Dr. Halffter was whether conservation should even be attempted at time when demands for development are so intense. The answer to this appears to lie in the improbability that the present intensity of demands will ever let up. It is this very intensity that makes act now all the more urgent. Even if adverse aspects of development can only be slightly ameliorated at present, a continuous effort in this direction is needed until sufficient public support is generated to meet issues of environmental significance head on and produce an improving rather than a deteriorating environment.

Dr. Halffter also expressed doubt as to the merits of local work such as that which might be done in Biosphere Reserves or the use of Dr. Gomez Pompa's land use classification system unless it led to revised national policies. Yet this seminar has recognized a serious disparity between proclaimed national policies and practices on the ground. For this very reason, local examples of excellence appear to be a thoroughly adequate goal for the present. National adoption, if and when it comes, may well be the work of nonscientific components of society.

The presence of many young people in this seminar is encouraging, and especially that of officials concerned with public education. As environmental problems continue to grow, increasing support for change can be expected. When this time comes it will be important that the young generations carry part of the responsibility. These people are now students in the public schools. They must all be made aware of environmental values and problems. It will not, however, be necessary that they all become experts in order to shift public opinion toward better environmental management.

One or two participants referred to the need to develop land use practices without the importation of nutrients (application of inorganic fertilizers). We seem to need clarification of the implicit debt contracted when nutrients are exported through the harvest of crops, and the

¹ Paper presented at an International Seminar on SOCIAL AND ENVIRONMENTAL CONSEQUENCES OF NATURAL RESOURCES POLICIES, WITH SPECIAL EMPHASIS ON BIOSPHERE RESERVES, held in Durango, Durango, Mexico, April 8-13, 1980.

² Director, Institute of Tropical Forestry, USDA Forest Service, Rio Piedras, Puerto Rico.

aspect that fallow periods (long enough to compensate the system) may be incompatible with production requirements. Mexico has announced plans to build a fertilizer plant with a capacity adequate to supply each farmed hectare with something like 300 kilos of fertilizer each year. It is to be hoped that fertilizer trials can be conducted on degraded management soils. In some cases even a light application can double yields, and presumably reduce farmland requirements accordingly. This could reduce or at least postpone pressures on lands that might better be left in rest.

We have been told that Mexico's tropical high forest area has been drastically reduced. What is left, because it is unique, is probably as valuable as all former forests were, and deserves special conservation efforts. The concern for loss of species might well be concentrated in part on saving a good system of secondary forests, since these probably contain most of the species of the former primary forests. Results in Puerto Rico suggest that the loss in species may not be proportionate to that of primary forest area if a network of secondary forests can be saved.

Visits to Mapimi and La Michilia Biosphere Reserves¹

Gonzalo Halffter, Peter F. Ffolliott, and Warren P. Clary²

As mentioned in the Preface to these proceedings, this seminar placed special emphasis on the consideration of natural resources policies that can impact Biosphere Reserves. By definition, Biosphere Reserves are areas of land designated by the Man and the Biosphere (MAB) Program to form a basis, within the natural and social sciences, for rational use and conservation of that portion of the earth's crust and lower atmosphere which contains life. Of particular interest to the participants at the seminar, was policies affecting those parts of Biosphere Reserves that are subject to manipulation by man. It is from these areas that people living on or adjacent to Biosphere Reserves commonly derive a variety of products and uses. Many of these people are entirely dependent on Biosphere Reserves for their livelihood and natural resources policies affecting Biosphere Reserves are of extreme importance to them.

Upon the completion of the formal and informal discussions which formed the core of the seminar, participants visited Mapimi and La Michilia Biosphere Reserves in the State of Durango, Mexico, to observe in-situ social and environmental consequences of natural resources policies imposed on these areas. Unfortunately, it was not possible for the participants to visit both of the Biosphere Reserves. Therefore, this summary has been prepared to highlight the visits.

MAPIMI BIOSPHERE RESERVE

The Mapimi Biosphere Reserve is situated northeast of the town of Ceballos, Durango, in the point formed by the boundaries of the States of Durango, Chihuahua, and Coahuila. The Reserve lies in a basin surrounded by small mountain ranges in a large catchment area known as Bolson de Mapimi. No legal boundaries have been fixed for the Reserve, but work has begun on a area of 20,000 hectares, regarded as the core zone, surrounded by a large buffer area. An association has been formed under the

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²Director, Institute of Ecology, Apartado Postal 18-845, Mexico 18, D.F.; Professor, School of Renewable Natural Resources, University of Arizona, Tucson, Arizona, USA; and Principal Range Scientist, USDA Forest Service, Intermountain Forest and Range Experiment Station, Ogden, Utah, located at Shrub Sciences Laboratory, Provo, Utah, USA.

authority of the Government of the State of Durango and the scientific direction of the Institute of Ecology to regulate the Reserve. It comprises the public authorities and graziers in the area and appropriate federal authorities. The region has had little disturbance except for sporadic hunting and, to a lesser degree, extensive stock raising. For the time being, all hunting has been voluntarily suspended, especially that of the desert tortoise. The peasants supervise observance of this ban.

The Mapimi Reserve is a part of the Chihuahuan arid zone. Microphyllous shrub species provide its character. Creosotebush is the characteristic plant determining the general physiognomy of the area, together with fleshy leaved or thick stemmed species, and large expanses of tobosa grass. Noteworthy fauna include the mule deer, giant tortoise (a species in danger of extinction), coyote, lynx, and puma.

The predominant physical features include alluvial deposits of recent Pleistocene materials and outcrops of igneous rock from the Tertiary period. There are isolated mountains, extensive interconnected plains, and a spring in the core zone. Elevations are 1,100 to 1,350 meters. Average annual rainfall is 200 millimeters, and the mean monthly temperature varies between 11 and 28 degrees Centigrade.

A "Laboratory of the Desert" has been constructed which provides excellent support facilities for scientific endeavors. Several institutions (foreign and domestic) are already undertaking a large number of studies. A number of publications have been completed concerning this work.

After the International Seminar, a group of interested participants traveled by special bus to Gomez Palacio. The following day, participants were transported to Mapimi by small airplane. Two days were spent in journeys on the Reserve, led by Dr. Halffter and other scientists who explained studies of herpetofauna, ecophysiology of dominant reptile species, the biology of the desert tortoise, the biology of raptorial birds, and the regeneration of desert vegetation after overgrazing, fire, and various types of human activity (fig. 1). Also included in the experience was a desert sandstorm which truly lived up to Dr. Halffter's statement that "Some of the desert storms at Mapimi are very impressive!"

LA MICHILIA BIOSPHERE RESERVE

La Michilia is a large plateau 145 kilometers southeast of the city of Durango. The Reserve



Figure 1.--Visit to Mapimi Biosphere Reserve.

comprises 42,000 hectares, 7,000 hectares of which are an integral preserve with the remaining 35,000 hectares a buffer area. In the buffer area, livestock grazing and controlled harvesting of timber is permitted, while complete legal protection of flora and fauna exists within the preserve.

Pine-oak forests constitute a major vegetation type, with juniper-oak woodlands and grasslands comprising other vegetative types found on differing topographic areas. Elevations range from 2,250 to 2,600 meters; on two sides, mountains rise to 2,850 meters. Soils, mostly clay and sand, are derived, in part, from igneous rock. Creeks and temporary lakes constitute the water sources. Precipitation averages 500 to 700 millimeters per year, and temperatures fluctuate from 12 to 28 degrees Centigrade.

La Michilia Biosphere Reserve has had little development. To date, scientific research in the reserve has centered around studies of flora and



Figure 2.--Visit to La Michilia Biosphere Reserve.

fauna, while other studies have been conducted on cattle development and range management, industrial use of regional products of agriculture, new crops to utilize the labor force, investigation of food sources, and improvement of sanitary conditions. Some of the research findings have been summarized in various publications.

During a two-day visit to La Michilia following the seminar, 16 participants, lead by Sonia Gallina and Exequiel Ezcurra of the Institute de Ecologia, visited areas set aside for baseline investigations of: vegetative composition and growth patterns; white-tailed deer biology and habitat requirements; range management and cattle development; small rodent and reptile population densities; and water development and transfer systems (fig. 2). These investigations and others are being conducted under the direction of scientists at the Institute of Ecology, Mexico City, and to furnish a basis for the assessment of man's impacts on the environment.

LIST OF INVITEES

FERNANDO ALBA ALDAVE
Consejo Nacional de Ciencia y Tecnologia
Insurgentes Sur No. 1677
Mexico 20, D.F.

LAURA ALCALA DE ZORRILLA
Calle San Bernardino No. 17-204
Col. del Valle
Mexico 12, D.F.

HUMBERTO ALVARADO SANCHEZ
Director de la Universidad Autonoma Agraria
"Antonio Narro"
Colonia Buenavista
Saltillo, Coahuila
Mexico

AGUSTIN AYALA-CASTANARES
Coordinador de la Investigacion Cientifica
Universidad Nacional Autonoma de Mexico
Apartado Postal 70-157
Ciudad Universitaria
Mexico 20, D.F.

MANUEL BENITEZ
Jefe de Parques y Fauna Silvestre
DIGENARE
Apartado Postal 2265
San Salvador, Rep. de El Salvador

ERNESTO BONDAY
Ministerio de Recursos Naturales
Blvd. Miraflores
Tegucigalpa, Honduras

JAVIER CASTROVIEJO BOLIVAR
Director de la Estacion
Biologica de Donana
Sevilla, Espana

M. RUPERT CUTLER
Assistant Secretary for Natural
Resources and Environment
Office of the Secretary Room 212A
Washington, D.C. 20250
USA

WARREN P. CLARY
Principal Range Scientist
Intermountain Forest and Range Experiment Station
USDA Forest Service
735 North 500 East
Provo, Utah 85601
USA

ENRIQUE COLLADO
Comision Coordinadora para el Desarrollo
Agropecuario del Distrito Federal
Av. Adolfo Ruiz Cortinez #3313
San Jeronimo Lidice
Mexico 20, D.F.

MIGUEL ANGEL CUADRA
Director de Programas Especiales de la
Secretaria de Programacion y Presupuesto
Fray Servando No. 77, 12º piso
Mexico D.F.

MARIO DARY
Jardin Botanico
Avenida de la Reforma 0-63
Zona 10
Guatemala

ABRAHAM DE ALBA
Instituto de Ecologia, A.C.
Apartado Postal 18-845
Mexico 18, D.F.

EDMUNDO DE ALBA
Director General de Investigacion
Cientifica y Superacion Academica
Secretaria de Educacion Publica
Insurgentes Sur 2387, 4º piso
Mexico 20, D.F.

VICTOR DE LA BARRERA FRAIRE
Director del Instituto Tecnologico
Regional de Durango
Av. 20 de Noviembre Sin No.
Durango, Dgo.
Mexico

EDUARDO LEON DE LA PENA
Tesoreria del Gobierno del Estado de
Durango
Durango, Dgo.
Mexico

ROLANDO W. DELASSE F.
Direccion General de Reservas y
Areas de Recreacion SARH
Netzahualcoyotl 109
Mexico 1, D.F.

IRVING DIAZ
Director
Instituto de Recursos Naturales
Ministerio de Desarrollo Agricola y Ganadera
Las Cumbres Ciudad de Panama
Panama

LANDO ELIZONDO MORALES
Director Ejecutivo
Instituto de Tierras y Colonización
San José
Costa Rica

ERIQUEL EZCURRA
Instituto de Ecología, A.C.
Apartado Postal 18-845
México 18, D.F.

TER F. FFOLLIOTT
Professor School of Renewable Natural Resources
Biological Sciences East Building
College of Agriculture
University of Arizona
Tucson, Arizona 85721
USA

A FLASHNER
Person 327 depto. 3A
Monica Polanco
México 5, D.F.

DRO GALINDO
Director Emeritus
Gas Memorial Laboratory
P.O. Box 935
Dade County, Miami 34002
USA

NIA GALLINA
Instituto de Ecología, A.C.
Apartado Postal 18-845
México 18, D.F.

ELVADOR GAMIZ FERNANDEZ
Gobernador Constitucional del
Estado de Durango
Palacio de Gobierno
Durango, Dgo.
México

JUARDO GARCIA PUEBLA
Gobierno del Estado de Sonora
Hermosillo, Son.
México

ONISIO GARZA SADA
Presidente de Empaques de Carton Titan
Universidad 2071
Santerrey, N.L.
México

STON CANO
Gobierno del Estado de Sonora
Hermosillo, Son.
México

TURO GOMEZ POMPA
Presidente del Comité MAB-México
Instituto Nacional de Investigaciones
Forestales y Recursos Bioticos
Colegio Militar No. 7
Tampala, Veracruz
México

RAMIRO GONZALEZ DEL SORDO
TURBOCAL
Secretaría de Turismo
Baja California
México

GONZALO HALFFTER
Director
Instituto de Ecología, A.C.
Apartado Postal 18-845
México 18, D.F.

VIOLETA HALFFTER
Instituto de Ecología, A.C.
Apartado Postal 18-845
México 18, D.F.

ROBERT L. HERBST
Assistant Secretary for Fish and Wildlife,
and Parks
Office of the Secretary Room 3156
U.S. Dept. of the Interior
Washington, D.C. 20240
USA

CARLOS HERNANDEZ
Inventario Forestal
Ave. Progreso No. 5
Coyoacan
México 21, D.F.

DAVID E. HERRICK
Director
Rocky Mountain Forest and Range Experiment Station
USDA Forest Service
240 West Prospect Street
Fort Collins, Colorado 80521
USA

JAIME INCER
Director del Centro de Investigación
Científica
Banco Central de Nicaragua
Managua
Nicaragua

JORGE JENKINS
Director del Instituto de Recursos Naturales
Apartado Postal 5123
Managua
Nicaragua

DONALD R. KING
Director
Office of Environmental Affairs Room 7822
U.S. Dept. of State
Washington, D.C. 20520
USA

MULLY KUX
Office of Science and Technology
USAID
Washington, D.C. 20523
USA

CARLOS LENNERHOFFER
Instituto Nacional Forestal
(INAFOR)
7 Avenida 7-09
Zona 13
Guatemala

CASSIO LUISELLI FERNANDEZ
Asesor del C. Presidente de la Republica
Presidencia de la Republica
Los Pinos
Mexico D.F.

JOSE HUGO MARTINEZ ORTIZ
Rector de la Universidad Juarez del
Estado de Durango
Constitucion Sin. No.
Durango, Dgo.
Mexico

HECTOR MAYAGOITIA DOMINGUEZ
Director del Instituto Politecnico Nacional
Direccion General-IPN
Unidad Profesional de Zacatenco
Mexico 14, D.F.

ELISEO MENDOZA BERRUETO
Subsecretario de Educacion Superior
e Investigacion Cientifica de la
Secretaria de Educacion Publica
Insurgentes Sur 2387, 4º piso
Mexico 20, D.F.

RICARDO MIER AYALA
Director de Bioconservacion, A.C.
Berlin 16 "A"
Col. Juarez
Mexico 6, D.F.

JOSE LUIS MOYA ORTEGA
Director Adjunto de Desarrollo Cientifico del
Consejo Nacional de Ciencia y Tecnologia
Insurgentes Sur 1677, 4º piso
Mexico 20, D.F.

SERGIO MANUEL VARDA HERNANDEZ
Subdirector del Inventario Forestal
Av. Progreso No. 5
Coyoacan
Mexico 21, D.F.

ALVARO NORMA SUINAGA
TURBOCAL
Secretaria de Turismo
Baja California
Mexico

SAMUEL OCANA
Gobernador Constitucional
del Estado de Sonora
Palacio de Gobierno
Hermosillo, Son.
Mexico

ARMANDO OCHOA
Director de Graduados y de
Investigacion Cientifica y Tecnologica
del Instituto Politecnico Nacional
Edificio de la Direccion General, 3º piso
Unidad Profesional de Zacatenco
Mexico 14, D.F.

EUGENIA OLGUIN
Instituto de Ecologia, A.C.
Apartado Postal 18-845
Mexico 18, D.F.

SILVIO OLIVIERI
Instituto Nacional de Investigaciones
sobre Recursos Bioticos
Heroico Colegio Militar No. 7
Jalapa, Veracruz
Mexico

MARIO OSORIO
Director del Centro Interdisciplinario
de Investigacion para el Desarrollo Integral
de la Comunidad Rural
Vicente Guerrero, Dgo.
Mexico

ROBERTO OTTO
Environmental Office Agency for International
Development Latin American Countrier Development
Resources LAC/DR. Department of State
Washington, D.C. 20520
USA

DANIEL PAMANES GARCIA
Escuela Medico Veterinaria de Durango
Carretera Durango-Mezquital Km. 11.5
Durango, Dgo.
Mexico

CARLOS ENRIQUE PENA LIMON
Hermosillo, Son.
Mexico

RAUL RANGEL
Director de la Escuela Medico Veterinaria
de Durango
Carretera Durango-Mezquital Km. 11.5
Durango, Dgo.
Mexico

WILLIAM O. RASMUSSEN
Professor School of Renewable Natural Resources
325 Biological Sciences East Building
College of Agriculture
The University of Arizona
Tucson, Arizona 85721
USA

PEDRO REYES-CASTILLO
Subdirector
Instituto de Ecologia, A.C.
Apartado Postal 18-845
Mexico 18, D.F.

JOSE MARIA RODRIGUEZ DE LA GUARDIA
Rep. de Costa Rica

ANDRES MARCELO SADA
Director General del Grupo CYDSA
Av. Ruiz Cortinez 2333
Monterrey, N.L.
Mexico

ANGEL RUBEN SALAS CUEVAS
Direccion General Fauna Silvestre
SARH. Netzahualcoyotl 109, 1º piso
Mexico 1, D.F.

JOSE SARUKHAN KERMEZ
Director del Instituto de Biologia
Universidad Nacional Autonoma de Mexico
Mexico 20, D.F.

FRANCISCO SERRANO
Jefe de Investigacion del Medio Ambiente
Apartado Postal 2265
San Salvador
Republica del Salvador

VALENTINA SERRANO
Instituto de Ecologia, A.C.
Apartado Postal 18-845
Mexico 18, D.F.

MANUEL SERVIN MASSIEU
Asesor de la Direccion General de Investigacion
Cientifica y Superacion Academica de la
Subsecretaria de Educacion Superior e Investigacion
Cientifica de la S.E.P.
Insurgentes Sur 2387, 4º piso
Mexico 20, D.F.

GUILLERMO SEVILLA
Viceministro de Recursos Naturales
Ministerio de Recursos Naturales
Bulevard Miraflores
Tegucigalpa, Honduras
Honduras

RODRIGO SILVA
Director de la Escuela de
Agricultura y Zootecnia de Venecia
Ejido Venecia, Gomez Palacio, Dgo.
Mexico

GERALD R. STAIRS
Director Center for Resource and Environmental
Policy Research
School of Forestry and Environmental Studies
Duke University
Durham, North Carolina 27706
USA

RAFAEL TIJERINA MORALES
DUMAC
Proconservacion y Desarrollo de las
Aves Migratorias
Ave. Constitucion Pte. 1527, 1º piso
Monterrey, Nuevo Leon
Mexico

JOSE TRUEBA
Jefe del Departamento de Promocion Social
de la Direccion General de Reforestacion
y Manejo de Suelos Forestales
Netzahualcoyotl 109, 9º piso
Mexico 1, D.F.

JEFF TSCHIRLEY
AID, Environmental Program
Office of Science and Technology
National Park Service
Washington, D.C. 20240
USA

ANTONIO UGARTE
Director de Asesores del C. Presidente
de la Republica, Presidencia de la Republica
Los Pinos
Mexico D.F.

JORGE VILLAGOMEZ CABRERA
Secretaria de Programacion Y Presupuesto
Pino Suarez 100 Ote.
Durango, Dgo.
Mexico

AVELINO VILLASALAS
Subsecretario Forestal y de la Fauna
SARH., Insurgentes Sur No. 476, 12º piso
Mexico 7, D.F.

ROBERT WILLCOX
Science Counselor
U.S. Embassy
Avenida Reforma
Mexico

RODRIGO ZELEDON
Presidente
Consejo Nacional de Investigaciones
Cientificas y Tecnologicas
Univ. de Costa Rica
Apdo. Postal 10318
San Jose
Costa Rica

Investigators of:

Centro Interdisciplinario de Investigacion
para el Desarrollo Integral de la Comunidad
Rural Vicente Guerrero, Dgo.
Mexico:
JORGE TENA
SOCORRO GONZALEZ
AGUSTIN MERE
LUIS CABELLO GUTIERREZ
ELENA CONTRERAS
DANIEL PAMANES

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Social and environmental consequences of natural resources policies, with special emphasis on biosphere reserves [Proc. International Seminar, April 8-13, 1980, Durango, Mexico].
USDA Forest Service General Technical Report RM-88. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado, 57 p.

The objective of this seminar was to promote international cooperation among natural resources policy makers, scientists, and educators within the framework of the International Man and the Biosphere program. Included are 20 invited and volunteer papers, plus a summary of visits to La Michilia and Mapimi Biosphere Reserves.



Rocky
Mountains



Southwest



Great
Plains

U.S. Department of Agriculture
Forest Service

Rocky Mountain Forest and Range Experiment Station

The Rocky Mountain Station is one of eight regional experiment stations, plus the Forest Products Laboratory and the Washington Office Staff, that make up the Forest Service research organization.

RESEARCH FOCUS

Research programs at the Rocky Mountain Station are coordinated with area universities and with other institutions. Many studies are conducted on a cooperative basis to accelerate solutions to problems involving range, water, wildlife and fish habitat, human and community development, timber, recreation, protection, and multiresource evaluation.

RESEARCH LOCATIONS

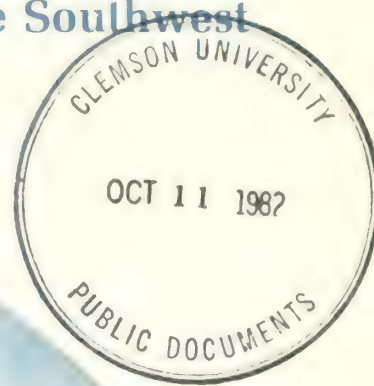
Research Work Units of the Rocky Mountain Station are operated in cooperation with universities in the following cities:

Albuquerque, New Mexico
Bottineau, North Dakota
Flagstaff, Arizona
Fort Collins, Colorado*
Laramie, Wyoming
Lincoln, Nebraska
Lubbock, Texas
Rapid City, South Dakota
Tempe, Arizona

*Station Headquarters: 240 W. Prospect St., Fort Collins, CO 80526

Selection and Monitoring of Avian Indicator Species: An Example From a Ponderosa Pine Forest in the Southwest

Robert C. Szaro and Russell P. Balda



General Technical Report RM-89
Rocky Mountain Forest and
Range Experiment Station
Forest Service
U.S. Department of Agriculture

Selection and Monitoring of Avian Indicator Species: An Example From a Ponderosa Pine Forest in the Southwest

**Robert C. Szaro, Research Wildlife Biologist
Rocky Mountain Forest and Range Experiment Station¹**

and

**Russell P. Balda, Professor of Biology
Northern Arizona University**

Abstract

A critical discussion of the factors involved in selecting an indicator species is highlighted by the examination of a case study. The pygmy nuthatch and violet-green swallow are suggested as indicator species for lightly cut to old growth southwestern ponderosa pine. The monitoring of avian species could best be accomplished by the variable circular-plot method.

¹Headquarters is in Fort Collins, in cooperation with Colorado State University. Research reported here was conducted at the Station's Research Work Unit at Tempe, in cooperation with Arizona State University.

Selection and Monitoring of Avian Indicator Species: An Example From a Ponderosa Pine Forest in the Southwest

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Management Implications

New rules and regulations set forth in section 219.12 on Forest Planning Actions (Federal Register 1979) require the USDA Forest Service to develop forest plans that will maintain viable populations of all existing native vertebrate species in planning areas and to maintain and improve habitat of management indicator species.

In selecting bird species for use as indicator species, and managers should consider several factors: (1) Residency status (i.e., summer, winter, or permanent resident), (2) foraging and/or nesting substrate, (3) adequate data base, (4) ease of monitoring, (5) sensitivity to habitat perturbations, (6) sensitivity to environmental fluctuations, (7) the condition or range of conditions a given species will "indicate," and (8) biogeographic considerations based on fragmentation of the habitat. Rare species may need to be used in the eighth case. Unfortunately, although limited information on many species precludes their selection as indicators, regulations require species to be selected in a relatively short period of time without the luxury of additional research to help in this process. Therefore, forest biologists and researchers with many years experience in a particular locality should base the selection on the best available information by both. It is unrealistic to expect a forest biologist with limited experience on a given forest to select species that might best indicate habitat degradation or condition.

Many forests within a given region have similar types of habitats. Forest biologists conferring among themselves and consulting with university personnel and other source agencies (e.g., U.S. Fish and Wildlife Service, State Game and Fish Departments) should be able to choose several species to meet the previously mentioned criteria. The species selected should always be considered as being on probation; that is, new data should be used to cull species from and add species to the list. When possible, managers within a region should attempt to select the same species within similar habitats.

Many methods of estimating bird numbers have been tried with varying degrees of success. We believe that the new technique, the variable circular-plot method, should be used for monitoring avian indicator species. This method has the advantages of (1) ease of setting up the plot, (2) accurate determination of sampling effort, (3) more accurate relation of habitat correlates to bird species and numbers, and (4) elimination from density estimations of the time spent watching the path of travel.

Introduction

As defined by the regulations, indicator species include at least: (1) Endangered and threatened plant and animal species, (2) species commonly hunted, fished, or trapped, (3) species with special habitat needs, and (4) additional plant or animal species selected because their population changes are believed to indicate effects of management activities on the collective species of a major biological community or on water quality.

Species in the first two categories have already been defined for the land manager: Threatened and endangered species appear on federal and state lists, and the species subject to hunting, fishing, and trapping are determined by state departments of fish and game. The land manager should be sure to use the current versions of such lists. When choosing species within these categories as indicators, the land manager should also apply the same general considerations used in the following example of selecting avian indicators in a Southwest ponderosa pine (*Pinus ponderosa*) forest.

We will concentrate on the selection of indicator species in the third and fourth categories, where species are selected because their population changes are indicative of management effects on an entire biological community or because of special habitat needs that must be met for their survival. These species serve as an "early warning system" of habitat changes because they are among the first species to respond to changes in habitat or because they respond to the smallest increments in change in habitat. Usually the manager must select more than one species of indicator in this category because any single species can serve as an indicator for only a narrow range of ecological conditions within a habitat type. For example, if an understory species were the only indicator species chosen for a ponderosa pine forest, inventories taken after heavy modification of the overstory would fail to show any effects of the treatment on overstory species. Thus, the manager must choose indicator species on the basis of the specific habitat factors which must be monitored. Because decisions based on the response of these indicator species may affect forest practices employed for a decade or longer, errors in selecting such species may have long-term negative effects on forest structure and animal community structure.

An ideal indicator species should (1) be sensitive to habitat-induced stress, (2) be conspicuous by sight and sound, (3) be easy to recognize in the field without the observer having to capture the species to identify it, and (4) operate during the hours when man is active. These attributes are most evident in birds; therefore,

this paper deals with the selection and monitoring of birds as indicator species.

The relationship between habitat perturbation and avian population trends is an area of past and current research effort. Habitat alterations in the form of timber harvest (Hagar 1960, Kilgore 1971, Franzreb 1977, Szaro and Balda 1979a), burning (Marshall 1963, Bock and Lynch 1970), and other means (Karr 1968, Yeager 1955), have had a demonstrable effect on bird community structure. It now becomes critical to draw on all the available information to select viable indicator species from those species that reflect these effects.

In this paper we will examine two critical aspects of the indicator species problem. First, given the adequate data, how to choose those species best suited as indicators and, second, how to monitor avian species once they are selected as indicators.

Indicator Species Selection in Ponderosa Pine

The primary prerequisite for selecting an indicator species is to define the conditions and/or health of the community you wish to indicate. Bird species can be selected whose presence is indicative of forest conditions from old growth forests to clearcuts.

In the ponderosa pine forest, the forest manager has a degree of latitude in choice and application of timber harvest prescriptions (Szaro and Balda 1979b). The opening of dense canopy forests has been shown to increase bird species and abundance in Douglas-fir (*Pseudotsuga menziesii*), giant sequoia (*Sequoiadendron giganteum*), and ponderosa pine (Hagar 1960, Kilgore 1971, Szaro and Balda 1979a). However, the quality of the bird community changes with forest structure.

Species such as the hermit thrush,² red-faced warbler, western flycatcher, and pygmy nuthatch, found in old growth forest and only lightly disturbed areas, are replaced in moderately to heavily cut areas by species such as the western wood pewee, yellow-rumped warbler, and rock wren. Those species that are most sensitive to habitat perturbations potentially make the best indicator species.

An examination of 2 years of data from four different study sites reveals an array of species responses to habitat manipulation (table 1). Many breeding species found in ponderosa pine stands throughout Arizona—Coues flycatcher, acorn woodpecker, band-tailed pigeon, Virginia's warbler, pygmy owl, whip-poor-will, goshawk, brown creeper, Brewer's blackbird, pine siskin, olive warbler, Say's phoebe, and hepatic tanager—are too rare to be of any help as general community indicators (Balda 1969, Carothers et al. 1973, Szaro 1976). However, they may be useful as indicators of special habitat needs, such as the close association between acorn woodpeckers and Gambel oak (*Quercus gambelii*) (MacRoberts and MacRoberts 1976), or of special biogeographic considerations, as is the coppery-tailed trogon.

Table 1.—Habitat preferences and densities (2-year average— pair per 100 acres) of avian species in selected ponderosa pine forests in Northern Arizona

Preference and species	Untreated ^a	Silviculturally cut	Irregular strip cut	Severely thinner cut
No preference				
Common flicker	3.0	3.0	3.4	3.0
Hairy woodpecker	3.0	3.0	4.5	2.3
Steller's jay	7.5	4.5	5.3	5.3
Common nighthawk	3.0	1.5	3.0	3.0
Mourning dove	3.0	1.5	—	5.3
White-breasted nuthatch	6.8	11.3	10.5	7.5
Prefer nondisturbed or lightly disturbed areas				
Red-faced warbler	3.0	—	—	—
Hermit thrush	1.9	0.4	—	—
Western flycatcher	4.9	4.2	—	—
Pygmy nuthatch	14.3	16.5	6.0	1.9
Violet-green swallow	8.3	8.3	3.0	—
Black-headed grosbeak	3.3	3.0	1.5	—
Prefer nondisturbed or moderately disturbed areas				
Gray-headed junco	15.0	18.8	11.3	6.4
Mountain chickadee	5.3	5.3	4.5	0.8
Prefer moderately to heavily disturbed areas				
Western wood pewee	—	2.3	9.0	3.0
Robin	—	3.0	5.3	3.8
Broad-tailed hummingbird	6.0	4.1	12.0	9.8
Prefer heavily disturbed habitat				
Rock wren	—	—	7.2	4.5
Prefer lightly or moderately disturbed areas				
Grace's warbler	9.0	19.1	14.3	6.8
Yellow-rumped warbler	1.5	12.0	3.0	1.5
Western tanager	1.5	5.6	3.0	—
Western bluebird	4.5	7.9	13.5	5.8
Prefer lightly to heavily disturbed areas				
Chipping sparrow	2.3	6.0	9.0	4.5
Solitary vireo	3.0	6.0	9.0	6.0
Prefer oak groves				
Acorn woodpecker	—	—	—	3.0

^aSee Szaro and Balda (1979b) for a more complete description of the study areas. Areas are listed in order of descending foliage volume.

Before we can make any decision on community indicators, we need to review current timber management practices in southwestern ponderosa pine stands. The commonly used silvicultural system in southwestern ponderosa pine today is the shelterwood system (Schubert 1974). This system is designed to produce even-aged stands. However, with prior planning, timber management activities in southwestern ponderosa pine can generally provide multiple use benefits (Brown et al. 1974).

²Scientific names of birds are listed in the appendix.

A frequent objective of timber management is the highest possible sustained timber yield (Schubert 1974). The shelterwood system involves managing each stand at a growing stock level of 60 square feet basal area per acre. At the first year of a new rotation there should be 25 trees averaging 22-24 inches in diameter. Eleven trees per acre will be marked to be left for shelter and as a seed source (about 40 square feet basal area). The remaining 14 trees will be removed. After a regeneration period of 10 years the overstory will be removed. At the 20th year, the new stand will average 11 inches in diameter and will be commercially thinned to 10 square feet. Subsequent intermediate cuts, starting with a commercial thinning at age 40, follow at 20-year intervals until the 120th year, when the rotation is complete.

Timber management using the shelterwood system requires a considerable time span (approaching 60 years) before the trees average 11 inches in diameter and before one can expect a managed stand to contain most of the bird species found in a community. It probably is advisable to schedule stand treatments to avoid extensive adjacent areas within the first 60 years of rotation. A minimum stocking level of 54 square feet per acre is necessary to maintain bird densities and diversity in the ponderosa pine forest with undisturbed or only lightly thinned areas surrounding the periphery of much of the cut area (Szaro and Balda 1979b).

What species will best indicate the overall "health" of a bird community in a given ponderosa pine stand? We answer this question by examining the core species (those found on four or more sites and/or years) in a stand with a minimum of 60 square feet basal area per acre. Ideally, we need a mix of 2, 3, or 4 species with differing requirements for foraging, nesting, and wintering areas. We can narrow our selection by determining the sensitivity of species to changes in habitat structure (table 1). Six species, Steller's jay, common goshawk, common flicker, hairy woodpecker, white-breasted nuthatch, and mourning dove, are insensitive to most levels of habitat disturbance short of total foliage removal. Obviously these species would make poor indicators. Other core species that probably could be poor indicators because of their scattered occurrence throughout structural types are listed in table 1.

One can argue against selecting summer residents because their populations can be highly influenced by winter weather conditions on and off the breeding grounds during the nonbreeding season (Fretwell 1972). This is not to imply that permanent residents are not affected by winter weather, but that their breeding and summer densities might be modified by habitat quality (Kricher 1975). Permanent residents are species whose densities are determined primarily by the habitat configuration of the pine forest (Balda and Gaud³). Summer residents, in contrast, make only a brief

³Balda, Russell P., and William S. Gaud. 1980. A model to predict density and diversity of breeding birds in the ponderosa pine forest. Northern Arizona University, Flagstaff, Ariz., and Rocky Mountain Forest and Range Experiment Station, Tempe, Ariz. Unpublished manuscript.

3-month appearance that occurs during a peak in productivity of various food types during spring and summer. Productivity appears to be closely correlated with prior winter weather conditions. Thus, the densities of summer residents may reflect prior winter conditions.

Similarly, one can argue against including either foliage or ground nesting species, as few species of permanent resident birds in the ponderosa pine forests are not cavity nesters and those that are not, are poor indicators. For example, the Steller's jay is found throughout the ponderosa pine forest with no discernable preference to any particular habitat configuration. Thus, although limiting the possible choices of species to permanent resident, cavity nesting species might be overly restrictive in that the number of species to choose from is reduced, it is our view that these species are more likely to reflect actual changes in habitat conditions.

Species with low densities, even though some exhibit definite habitat preferences and may be good indicators, would be difficult to monitor. What needs to be guaranteed is that the species finally selected is an indicator of these "rarer" species.

An exception to picking a summer resident or a species with low density would occur when the manager wants to indicate a very narrow range of conditions within a vegetative association. Noon et al. (1979) suggest that extensive habitat disturbance may have its most pronounced effects on the rare species of a community. Thus, the determination of habitat features which support these rare species should be of prime importance. Their consistent rareness even in their preferred habitat is indicative of an extreme specialization to some aspect of their environment (Noon et al. 1979). For example, two rare species, the western flycatcher and hermit thrush, are both excellent indicators of old growth forest with a dense overstory.

A close examination of permanent resident cavity nesters with adequate densities for a sampling program narrows the possible choices to two: (1) pygmy nuthatch and (2) violet-green swallow. Both are relatively easy to observe and census. Balda and Gaud³ developed models to predict density and diversity of breeding birds in the ponderosa pine forest (using the data from table 1 and several other sites). When 10 weather factors and 11 factors of foliage structure were used in a multiple regression analysis, no weather factors entered into the model for either the pygmy nuthatch or the violet-green swallow. In fact, 83% of the variability in pygmy nuthatch densities was explained by total foliage volume (63.4%), snag density (11.6%), and trunk volume (7.8%). Both foliage volume and snag density were positively associated, whereas trunk volume was negatively associated, with pygmy nuthatch density. In contrast, three negatively associated factors, Gambel oak foliage volume (66.3%), trunk volume (9.7%), and sapling volume (16.7%), predicted 93% of the variability in violet-green swallow density. Therefore, in choosing these two species we are selecting for a ponderosa pine stand with high foliage volume and snag densities with little Gambel oak and few pine saplings. These are the same factors necessary to

maintain the populations of most other typical ponderosa pine breeding birds.

Other species can be used to indicate other habitat conditions. For example, the rock wren is only present on heavily disturbed or clearcut habitats. Moreover, the western wood pewee might be considered as an indicator of the bird community in more open ponderosa pine stands.

We should emphasize that in our selection process we are choosing species that are indicative of a particular set of habitat conditions. Then we are looking at what species are found under the same set of conditions. The correlation between the density of the indicator species and other species of the avian community is not directly established by this method. However, an examination of the density data (table 1) shows that, when we have good densities of pygmy nuthatch and violet-green swallow, we also have good densities of most other ponderosa pine forest bird species.

Species Monitoring Methods

How best to estimate bird populations is a question still embroiled in controversy. Currently the two most widely accepted techniques are the territory mapping method (Williams 1936, Kendeigh 1944, Enemar 1959) and the line transect method (Emlen 1971, 1977; Järvinen 1976, 1978; Järvinen and Väisänen 1975, 1976a, 1976b; Järvinen et al. 1976). The territory mapping method is sometimes considered the most accurate means of estimating population densities of breeding territorial birds (see Best 1975 for discussion of its limitations). However, its use (by definition) is limited to the breeding season and is not applicable in censusing bird populations in the nonbreeding seasons (Franzreb 1977). The line transect method can be used any time of the year but usually requires a census line of at least a mile in length. The required length of the transects is a problem in many small "island" habitats or in habitats with heterogeneous or patchy structure. Additionally, it is virtually impossible to obtain confidence limits on bird population estimates from the territory mapping method, and difficult at best with the line transect method to sample enough transect lines to get a valid statistical estimate (Eberhardt 1978, Burnham et al. 1980). Certainly by increasing the number of visits in both techniques, the researcher can improve the efficiency and accuracy of the technique (Järvinen et al. 1978, Svensson 1978).

Reynolds et al. (1980) developed a new technique, the variable circular-plot method, which may prove to be the best method to monitor indicator species. Briefly, the technique involves establishing stations within a plant community at equal intervals along a transect or scattered within a habitat type (avoiding edges) in such a manner as to avoid multiple detections of the same bird at different stations. The observer records each bird seen or heard during the count period (8 minutes for closed canopy forests) and estimates the horizontal distance to its location when first observed. The den-

sity of each species is then determined by inspecting a histogram of the number of individuals per unit area in concentric bands of predetermined widths about the stations. An inflection point (i.e., the distance from the point where the density begins to decline) is determined, and the number of individuals occurring within this distance (radius X) is divided by area of radius X to estimate birds per unit area. Bird abundance measures must be keyed to an area of given size and not a relative index that does not take into account detectability differences, such as in the study by Webb et al. (1977).

Determination of the number of stations and/or sampling periods per station is based on the habitat, species abundance, and the size of the area to be sampled. For example, in Hawaii, density estimates of $\pm 30\%$ of mean density for most common species were obtained by sampling 56 stations or less (Reynolds et al. 1980). For rarer species, 210 stations were needed for density estimates of $\pm 50\%$ of mean density. For a $\pm 30\%$ estimate, 622 stations were required. A reduction in the number of stations required can be obtained by multiple sampling of the same stations. But, because of the correlation between estimates taken at the same station, the fewer times a given station is sampled the better the estimate of variability. Therefore, the number of stations sampled must carry most of the weight in developing estimates of precisions likely to be achieved with a given level of sampling. We recommend not sampling the same station more than three times. Obviously, there are tradeoffs involved in trying to determine the optimum number of stations and the number of times each station should be sampled. If the object of the sampling is to determine breeding bird abundance, then a single sample at a large number of points all sampled on the same day early in the breeding season would fail to estimate late breeding species. The converse is also true. For example, sampling a desert scrub habitat in late May would fail to census the male Costa's hummingbirds displaying on the plot. Any bird sampling design, therefore, should incorporate a combination of both a representative number of stations for a given area and either repetitive sampling at each station or, preferably, sampling different points in the same habitat at various times throughout the breeding season. For yearly trend information, data should be collected within a relatively tight time frame (i.e., a month) from one year to the next.⁴

In desert riparian and scrub habitats, Szaro and Jakle found that 14 stations sampled 4 times at 2-week intervals were sufficient to obtain density estimates of $\pm 50\%$ for 13 of the 23 breeding species on both study plots. Half the estimates were within $\pm 30\%$ of mean density. A greater number of sampling periods and/or sampling stations would have been necessary to obtain more accurate density estimates. However, no increase in the number of stations was possible in the desert riparian plot because of the limited size of the riparian area. An obvious question is how these est

⁴Personal communication with Jared Verner, USDA Forest Service, Pacific Southwest Forest and Range Experiment Station, Fresno, Calif., 1981.

ates compare to those obtained by more accepted techniques (i.e., the spot-map and line transect methods). Szaro and Jakle⁵ reported that, in desert riparian and scrub habitats sampled by both the spot map and variable circular-plot methods, all the spot map densities except one fell within the 95% confidence limits of their variable circular-plot estimates.

The variable circular-plot method has several advantages: (1) canopy birds can be more accurately censused because the observer is stationary and not spending time watching the path of travel; (2) habitat correlates at each station can be more accurately related to species abundance or absences because the areas censused are smaller and more discrete than with the other two methods; and (3) the sampling effort can be more accurately determined.

The application of the variable circular-plot method is as follows:

1. Determine the relative abundance of the species to be monitored. For example, common (more than 120 individuals/100 acres) or rare (fewer than 10 individuals/100 acres).

2. The number of stations required to establish the abundance of a species varies with the spatial distribution of individuals within a population, their abundance, and their conspicuousness in each season and habitat. We recommend that up to 56-64 stations be censused and then density estimates calculated. Sampling should be continued until the percent variation around the mean density reaches an acceptable level, i.e., 10, 20, or 30%. The sampling scheme should be designed so that more stations could be added properly if the need arises. The intensity of the sampling effort throughout the area in question must be maintained even as new stations are added.

Determine points at random throughout the habitat or on transect lines at a minimum of 350-foot intervals.

Sample each station by first waiting 1 minute and then recording the distance from the point to each bird seen or heard during 8-minute periods (closed habitat as a ponderosa pine association) or during 4-minute periods (open habitat such as a palo verde-saguaro (*Cercidium microphyllum*-*Cereus giganteus*) association). In practice, the time period should depend upon the detectability of the birds within each habitat.

Plot the density of a species in bands of 15-foot widths from 0 to 330 feet and then 30-foot widths from 330 to 660 feet (table 2). Singing males count as two individuals. Density per band is then calculated by the following formula:

$$BD = \frac{4.356 (10^6) (N)}{\pi (OR^2 - IR^2) (p) (f)}$$

where BD = band density on a 100 acre scale,

⁵Szaro, Robert C., and Martin D. Jakle. 1981. Comparison of variable circular-plot and spot-map methods for estimating avian densities in desert riparian and scrub habitats. Rocky Mountain Forest and Range Experiment Station, Tempe, Ariz. Unpublished manuscript

N = number of observations in the band, OR = the outer band radius, IR = the inner band radius, p = the number of sampling stations, and f = the frequency each station was sampled.

6. Determine the inflection point (IP). That is, determine the distance to the outermost edge of the band where the density of individuals per unit area (100 acres) in the next outermost band is less than 50% of the previous band. However, if the number of individuals per 100 acres in any one of the more distant bands exceeds 50% of the mean number of birds per 100 acres per band over all preceding bands, then, in this case, use this outermost edge of this band as the inflection point. Caution should be taken against the blind application of this method. The inflection point should be determined after a careful analysis of the data. As an alternative, Ramsey⁶ suggests plotting a cumulative frequency curve of the data and then determining the density estimate from the point of maximum slope of the curve. In our example in table 2, the inflection point is 90 feet.
7. The inflection point (determined separately for each species) is then used to calculate birds per 100 acres for each point for each count period. Use the formula:

$$\text{birds/100 acres} = \frac{4.356 (10^6) (N)}{\pi (IP^2)}$$

8. Overall density is then calculated by determining the mean ($\bar{y}$) and standard error (SE) of the individual estimates. In order to account for the correlation between sampling periods, SE should be calculated by the following:

$$v(\bar{y}) = \left(\sum_i S_i^2 + 2 \sum_{i < j} r_{ij} S_i S_j \right) / (p f^2) ; SE = \sqrt{v(\bar{y})}$$

Where S_i^2 is the among-station variance on the i^{th} sampling period, and r_{ij} is the correlation between sampling periods i and j . For our example, overall density of Lucy's warbler is 428 ± 97 birds/100 acres (table 3).

The variable circular-plot technique has the further advantage of probably being adaptable to censusing other vertebrate species. For example, the stations can be used as central locations for small mammal population estimates by modifying existing methods and setting live traps in a concentric pattern around the census point (Marten 1970, Nelson and Clark 1973, Geier and Best 1980, Seber 1973). Similarly, small reptiles and amphibians can be sampled using an array system of pit traps (Seber 1973, Heckel and Roughgarden 1979, Jones 1980).

In areas of larger, more uniform, and less complex habitats the line transect or strip count method might be considered an acceptable alternative because it allows the coverage of larger areas per unit of time (see Burham et al. 1980 and Eberhardt 1978).

⁶Personal communication with Fred Ramsey, Oregon State University, Corvallis, 1980.

Table 2.—Hypothetical example of data for Lucy's warbler obtained from seven variable circular-plot stations, each sampled twice

Observations					Observations			
Interval	Singing males	Others	Total	Band ^a density	Station	Sampling period	< 90 feet	Density ^a
<i>feet</i>								
0< 15	1	1	3	1320	1	1	3	514
15< 30	1	3	5	734		2	4	685
30< 45	2	3	7	616	2	1	2	342
45< 60	3	2	8	503		2	2	342
60< 75	2	2	6	293	3	1	2	342
75< 90 ^b	2	2	6	240		2	1	171
90< 105	1		2	68	4	1	3	514
105< 120	1		2	59		2	5	856
120< 135				0	5	1	0	0
135< 150	1		2	46		2	1	171
150< 165				0	6	1	2	342
165< 180				0		2	1	171
180< 195	1		2	35	7	1	2	342
195< 210				0		2	7	1198

^aBirds per 100 acres

^bInflection point

Table 3.—Example mean and standard error calculation for Lucy's warbler density (from data in table 2)

Computation Steps	
1. Correlation between sampling periods 1 and 2 (see Sokal and Rohlf 1973, page 271).	
$r_{ij} = 0.49$	
2. Calculate mean ($\bar{y}$) and standard deviation (s) for both sampling periods.	
$\bar{y}_1 = 342.29$	$s_1 = 171.33$
$\bar{y}_2 = 513.43$	$s_2 = 407.55$
3. Overall mean.	
$\bar{y} = 1/2(\bar{y}_1 + \bar{y}_2) = 427.86$	
4. Overall standard error.	
$v(\bar{y}) = [(171.33^2 + 407.55^2 + 2 \times (0.49) \times (171.33) \times (407.55))] / (7 \times 2^2)$	
$= 9474.2$	
$SE = \sqrt{9474.2} = 97.3$	

Conclusions

The management of forest lands requires a multiple use approach which is not inconsistent with maintaining viable bird populations. Species sensitive to habitat perturbations will be the best indicators. Preferably, they should include species with densities more influenced by habitat rather than environmental factors and species with high enough densities for a monitoring program to yield more than just simple presence or absence data. In the ponderosa pine forest, we suggest that the two species that best indicate the overall "health" of the bird community are the pygmy nuthatch and violet-green swallow.

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Appendix

Bird Common and Scientific Names

Common Name	Scientific Name
Band-tailed pigeon	<i>Columba fasciata</i>
Mourning dove	<i>Zenaida macroura</i>
Pygmy owl	<i>Glaucidium gnoma</i>
Whip-poor-will	<i>Caprimulgus vociferus</i>
Common nighthawk	<i>Chordeiles minor</i>
Costa's hummingbird	<i>Calypte costae</i>
Broad-tailed hummingbird	<i>Selasphorus platycercus</i>
Coppery-tailed trogon	<i>Trogon elegans</i>
Common flicker	<i>Colaptes auratus cafer</i>
Acorn woodpecker	<i>Melanerpes formicivorus</i>
Hairy woodpecker	<i>Picoides villosus</i>
Say's phoebe	<i>Sayornis saya</i>
Western flycatcher	<i>Empidonax difficilis</i>
Coue's flycatcher	<i>Contopus pertinax</i>
Western wood pewee	<i>Contopus sordidulus</i>
Violet-green swallow	<i>Tachycineta thalassina</i>
Steller's jay	<i>Cyanocitta stelleri</i>
Mountain chickadee	<i>Parus gambeli</i>
White-breasted nuthatch	<i>Sitta carolinensis</i>
Pygmy nuthatch	<i>Sitta pygmaea</i>
Brown creeper	<i>Certhia familiaris</i>
House wren	<i>Troglodytes aedon</i>
Rock wren	<i>Salpinctes obsoletus</i>
American robin	<i>Turdus migratorius</i>
Hermit thrush	<i>Catharus guttatus</i>
Western bluebird	<i>Sialia mexicana</i>
Solitary vireo	<i>Vireo solitarius</i>
Virginia's warbler	<i>Vermivora virginiae</i>
Olive warbler	<i>Peucedramus taeniatus</i>
Yellow-rumped warbler	<i>Dendroica coronata auduboni</i>
Grace's warbler	<i>Dendroica graciae</i>
Red-faced warbler	<i>Cardellina rubrifrons</i>
Brewer's blackbird	<i>Euphagus cyanocephalus</i>
Western tanager	<i>Piranga ludoviciana</i>
Hepatic tanager	<i>Piranga flava</i>
Black-headed Grosbeak	<i>Pheucticus melanocephalus</i>
Pine siskin	<i>Carduelis pinus</i>
Gray-headed junco	<i>Junco caniceps</i>
Chipping sparrow	<i>Spizella passerina</i>

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Szaro, Robert C., and Russell P. Balda. 1982. Selection and monitoring of avian indicator species: An example from a ponderosa pine forest in the Southwest. USDA Forest Service General Technical Report RM-89, 8 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

A critical discussion of the factors involved in selecting an indicator species is highlighted by the examination of a case study. The pygmy nuthatch and violet-green swallow are suggested as indicator species for lightly cut to old growth southwestern ponderosa pine. The monitoring of avian species could best be accomplished by the variable circular-plot method.

Keywords: Indicator species, ponderosa pine, monitoring methods, variable circular-plot method

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Rocky
Mountains



Southwest



Great
Plains

U.S. Department of Agriculture
Forest Service

Rocky Mountain Forest and Range Experiment Station

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Hydrologic Regimes of Forested Areas in the Beaver Creek Watershed

Malchus B. Baker, Jr.



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Malchus B. Baker, Jr., Hydrologist
Rocky Mountain Forest and Range Experiment Station¹

Abstract

The hydrologic regimes of watersheds in the Utah and alligator juniper woodland and ponderosa pine forest type on volcanic-derived soils along the Mogollon Rim in north-central Arizona are described. Winter precipitation is shown to be most important to the streamflow regimes in this area. The data indicate that the best opportunity for increasing water yield by vegetation manipulation is in the ponderosa pine type. Mean annual peak discharges are higher in the two juniper vegetation types and are more frequent in the summer than those occurring in the pine type.

¹Headquarters is in Fort Collins, in cooperation with Colorado State University.

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Management Implications

Winter precipitation is the precipitation which is most important to the streamflow regimes along the Mogollon Rim in Arizona. The mean peak water equivalent of the snowpack in the ponderosa pine type is inches (10 cm). Vegetation manipulation can affect snow accumulation and melt and evapotranspiration. Consequently, it can influence the major portion of annual streamflow, which is produced from the melting snow. However, longterm potential increases in water yield by vegetation manipulation are limited by the relatively small accumulation of snow.

Summer precipitation occurs at a time of high evaporation stress and high moisture demand by vegetation. The generally small summer storm events produce little water yield or flooding, even from storms with recurrence intervals of 25 and 50 years.

The inherently low water yield (10% of mean winter precipitation) from untreated Utah juniper watersheds on volcanic-derived soils limits this vegetation type from significantly increasing water yields. The naturally high water yield (37% of mean winter precipitation) from the alligator juniper watersheds and their characteristic low vegetation density, sparse litter cover, and soil type also limits the use of vegetation manipulation in this type. Water yield from the ponderosa pine type (33% of mean winter precipitation) has been shown to be responsive to vegetation manipulation.

Average annual peak discharges are characteristically higher in the two juniper vegetation types than in the pine type because of their soil type, vegetation density, and sparse litter cover. Annual peak discharges are also more frequent in the summer season from the juniper watersheds. Mean annual peak discharges of 117, 112, and 90 $\text{ft}^3 \cdot \text{s}^{-1} \cdot \text{mi}^{-2}$ (1.3, 1.2, and $0.03 \text{ m}^3 \cdot \text{s}^{-1} \cdot \text{km}^{-2}$) from the Utah and alligator juniper and pine type, respectively, do not adequately characterize the flood hazard from these untreated vegetation types. A few large flood events have skewed the distributions of the annual peak flows. Annual peak discharges that have been equalled or exceeded 50% of the time in the Utah and alligator juniper and pine types, respectively, are 32, 74, and 44 $\text{ft}^3 \cdot \text{s}^{-1} \cdot \text{mi}^{-2}$ (0.4, 0.8, and $0.05 \text{ m}^3 \cdot \text{s}^{-1} \cdot \text{km}^{-2}$).

Introduction

Demands for water from Arizona's National Forests continue to increase even as public demands for timber, range, and recreational uses are increasing. Although it is impossible to maximize all resource prod-

ucts and land uses from the same area, there are opportunities for managing forest land for an optimal mix of outputs determined by economic and environmental analyses. However, to manage our forest lands effectively, land managers first need baseline information on how watersheds behave under their natural conditions as well as how they respond to various types of management manipulations.

The Salt-Verde River Basin, along Arizona's Mogollon Rim, is the state's major water production area (fig. 1). Ponderosa pine forests and pinyon-juniper woodlands occupy nearly 50% of this watershed. The ponderosa pine type yields nearly one-half of the total runoff in the basin and the pinyon-juniper woodland yields approximately 10% (Barr 1956).

In the mid-1950's, the Forest Service initiated a number of watershed management studies to determine the feasibility of increasing water yields from the different vegetation types in the Salt-Verde Basin (Brown et al. 1974). The 275,000-acre (111,375-ha) Beaver Creek watershed was chosen to represent the pinyon-juniper and ponderosa pine types on volcanic soils along the

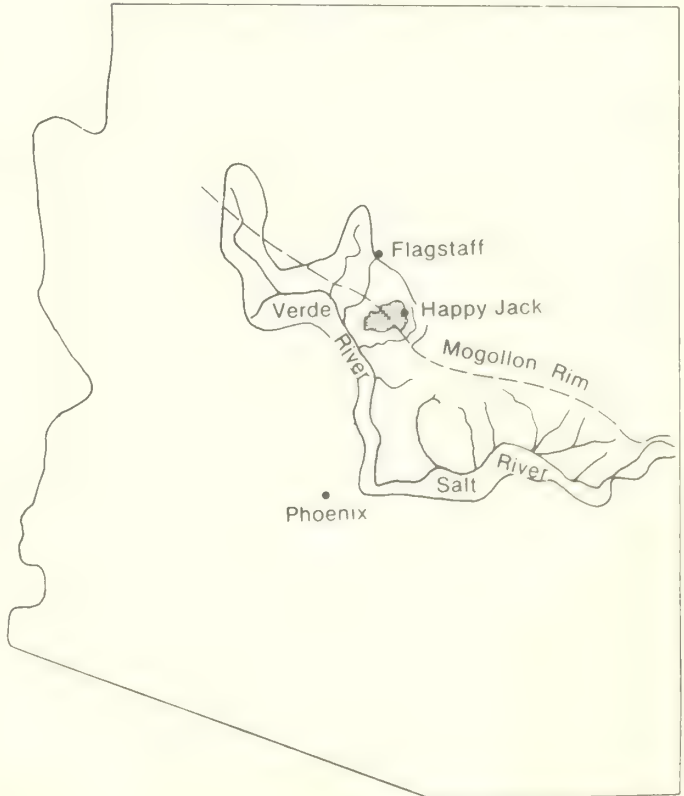


Figure 1.—Location of the Salt-Verde Basin and Mogollon Rim in Arizona. The Beaver Creek watershed is shaded.

Mogollon Rim. Because 57% of the ponderosa pine forest in the Salt-Verde Basin is on volcanic soils (the remaining 43% is on sedimentary parent material), knowledge of the hydrology on Beaver Creek can provide useful baseline data for land managers. This hydrologic information can also help provide an understanding of the hydrology of other naturally vegetated watersheds on volcanic soils along the Mogollon Rim. The intent of this paper is to present an analysis of research concerning the hydrologic regimes of the natural woodland and forested areas on Beaver Creek. The information is based on 22 years of research.

Study Area

The Beaver Creek Experimental area is in the Colorado Plateau physiographic province within the Mogollon Slope.² The regional dip of the Mogollon Slope is northeast; however, a major flexure north of the Beaver Creek Watershed (the Mormon Mountain anticline) reverses the regional dip in the Beaver Creek area.³ The drainage is situated across the Mogollon Rim, which separates the Colorado Plateau and the Verde Valley.

The Beaver Creek drainage ranges in elevation from 3,100 to 8,000 feet (945 to 2,438 m) and contains four vegetative types: semidesert, Utah juniper (*Juniperus osteosperma* (Torr.) Little), alligator juniper (*J. deppeana* Steud.), and ponderosa pine (*Pinus ponderosa* Laws.) (fig. 2). Soils are derived from parent materials

²Rush, R. W., and D. Smouse. 1968. *Geological investigations of experimental drainage basins 15-18 and Bar-M Canyon, Beaver Creek Watershed, Coconino County, Arizona. Rocky Mountain Forest and Range Experiment Station, Flagstaff, Ariz. (unpublished report).*

³Rush, R. W. 1965. *Report of geological investigations of six experimental drainage basins, Beaver Creek Watershed, Yavapai County, Arizona. Rocky Mountain Forest and Range Experiment Station, Flagstaff, Ariz. (unpublished report).*

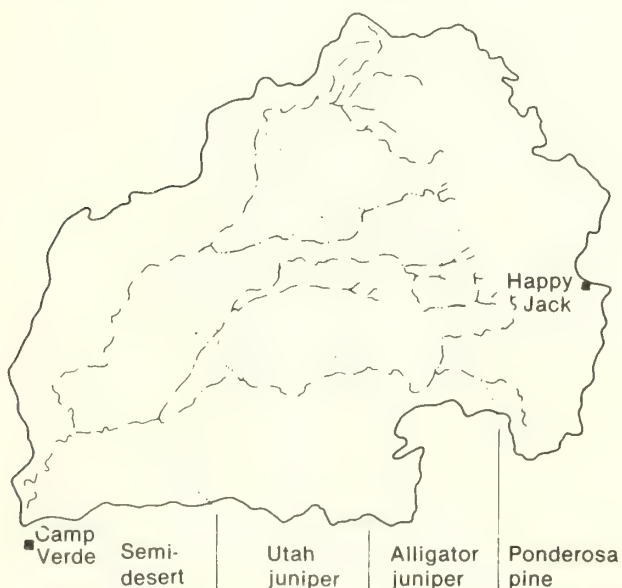


Figure 2.—The Beaver Creek Watershed.

of sandstone and limestone below the 5,000-foot (1,524-m) elevation and from basalt and volcanic cinders above. All experimental watersheds are above the 5,000-foot (1,524-m) elevation, and their soils range from clay to clay loams averaging 2.5 feet (0.7 m) in depth (Williams and Anderson 1967). Soils developed on these volcanic surfaces are generally dark in color, usually red, and have little free silica. They often have low permeability rates which restrict water infiltration and percolation.

Volcanic parent material covers the Beaver Creek area at depths from zero at the lower elevations to an estimated 1000 feet (305 m) near some of the cinder cones in the area.⁴ The average thickness is believed to be approximately 500 feet (152 m), based on the projected position of the erosion surface of the Kaibab Formation on which the volcanics were deposited.³

The sedimentary rocks below the volcanic cover are porous and permeable because of their origin and the abundant fracture systems developed in them. Water that penetrates the volcanic mantle may be expected to continue through the sedimentary beds to the regional water table, estimated to be between 1,000 and 2,000 feet (305 and 610 m) below the surface.³

Of the rock types exposed on Beaver Creek, the basaltic and andesitic lavas are the least porous and permeable. When unfractured, they are essentially impervious to water. The cinder deposits are highly porous even when cemented. Water falling on the cinder cones percolates downward and produces very little surface stormflow. However, because the cones are built upon a lava base, the permeability of this base determines whether the water continues downward to the regional water table or seeps out along the base of the pyroclastic material.

The general topography of the Beaver Creek area has developed as the result of outpouring of successive lava sheets that are inclined towards the Verde Valley.⁴ The slope-controlled distribution of stream has produced a subparallel drainage system of numerous, closely spaced streams.

In their untreated condition, the vegetation density of the Utah juniper averages 60 square feet per acre (14 m²/ha) of basal area; basal areas for the alligator juniper and ponderosa pine are 20 and 125 square feet per acre (5 and 29 m²/ha), respectively.⁵

Overland flow results from precipitation which does not infiltrate or pond in small soil surface depressions but moves downhill over the soil surface (Storey et al. 1964). Overland flow, if of sufficient quantity, is an important element in the formation of flood peaks (Linsley et al. 1958). Forest basins typically have permeable soils and relatively large soil water storage capacity that result in sustained flow and a relatively small

⁴Beus, S. S., R. W. Rush, and D. Smouse. 1966. *Geologic investigation of experimental drainage basins, 7-14, Beaver Creek Watershed, Coconino County, Ariz. Rocky Mountain Forest and Range Experiment Station, Flagstaff, Ariz. (unpublished report).*

⁵Ffolliott, Peter F. *Overstory inventories of the vegetation type on the Beaver Creek Watershed Evaluation Project. Office Reports. Rocky Mountain Forest and Range Experiment Station, Flagstaff, Ariz.*

ratio between floodflow and mean flow. Under typical forest conditions (except those areas where logging, grazing or fire has exposed mineral soil), overland flow is virtually absent (Lull and Reinhart 1972; Hewlett and Hibbert 1967).

The pinyon-juniper woodland type is on the Springerle soil series, which has a predominately clay texture. The infiltration rate for this series ranges from 0.8 to 2.5 inches (2.0 to 6.4 cm) per hour with a permeability rate of less than 0.05 inch (0.1 cm) per hour. Water storage capacity for this soil series is over 18 inches (46 cm).

The Brolliar soil series comprises about 90% of the area in the ponderosa pine forest type. The infiltration rate for this series ranges from 0.8 to 2.5 inches (2.0 to 6.4 cm) per hour, and it has a permeability rate that ranges from 0.05 to 0.2 inch (0.1 to 0.5 cm) per hour. Water storage capacity is between 6 and 18 inches (15.2 to 45.7 cm). The remaining 10% of the area is composed of the Siesta-Sponseller soil series, which has the same ranges of infiltration and permeability rates as the Brolliar soil series. Water storage capacity is over 18 inches (45.7 cm). When an upper soil horizon is thin and the permeability rate of the next lower soil horizon is limited, soil saturation of the upper soil horizon is rapid (Betson and Marius 1969). Such an area then becomes a source of streamflow, producing either surface or subsurface flow.

Watersheds, such as on Beaver Creek, with soils of low permeability and small soil water storage have high ratios of peak discharge to mean flow and often no flow between streamflow events. Streamflow typically stops shortly after the end of rainfall or snowmelt, even after precipitation events that have recurrence intervals of 100 years.

Stream gages were installed in the late 1950's and early 1960's within the Beaver Creek drainage to establish 20 experimental watersheds ranging in size from 66 to 16,000 acres (27 to 6,480 ha) (fig. 3). Four-

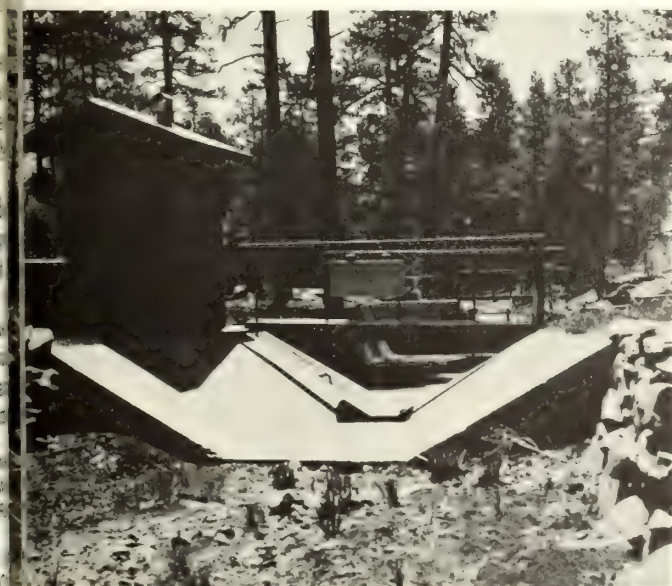


Figure 3.—Concrete trapezoidal flume of the type used on Watersheds 1-18 on Beaver Creek.

teen of the watersheds are in the ponderosa pine type, and six are in the pinyon-juniper type. The study area is discussed in detail in Brown et al. (1974) and Clary et al. (1974). The results of this study are based on measurements from 1958 through 1979.

Hydrologic Regimes

General Characteristics

The Beaver Creek watershed is in the plateau climatic region of Arizona. Two major precipitation seasons characterize this region. The most important is the winter season from October through April (fig. 4). Winter precipitation accounts for over 60% of the annual precipitation. Most of the remaining precipitation falls during July, August, and September.

Over a period of 22 years (1958-79), mean annual precipitation on Beaver Creek increased with elevation. Precipitation at the lower elevation of 3,180 feet (969 m) averages 11.70 inches (29.7 cm), increasing 3.3 inches (8.4 cm) for every 1,000-foot (305 m) increase in elevation along the axis of the watershed perpendicular to the Mogollon Rim.

Widespread, protracted, frontal storms and prolonged flows are common along the Mogollon Rim during the period from November through March and provide the major portion of annual water yield. Precipitation in May and October varies but is most nearly like that of the winter period. Precipitation in October is composed principally of storms that are preceded by dry weather. Therefore, much of the water from these storms is absorbed by dry soil and over a period of years contributes little to total streamflow.

Point rainfall intensities in Arizona are generally not excessive (Sellers and Hill 1974). However, cloudbursts occasionally produce up to 3 inches (8 cm) of rain in less than 30 minutes. These events are generally in the summer over the mountainous country, but they are much less frequent than the extremely light rain showers that barely wet the ground. Rainfall intensities greater than 4 inches (10 cm) per hour have only been recorded for durations of 15 minutes or less.

The greatest rainfall intensities ever recorded on Beaver Creek during the May-October period are (these were, except where noted, in the pine type in 1970):

Duration minutes	Intensity inches per hour
5	10.01
15	5.26
30	3.21 (Alligator juniper, 1960)
60	2.09 (Alligator juniper, 1960)
120	1.45
360	0.64
1440	.28

Differences between precipitation and streamflow may be assumed to represent total evapotranspiration

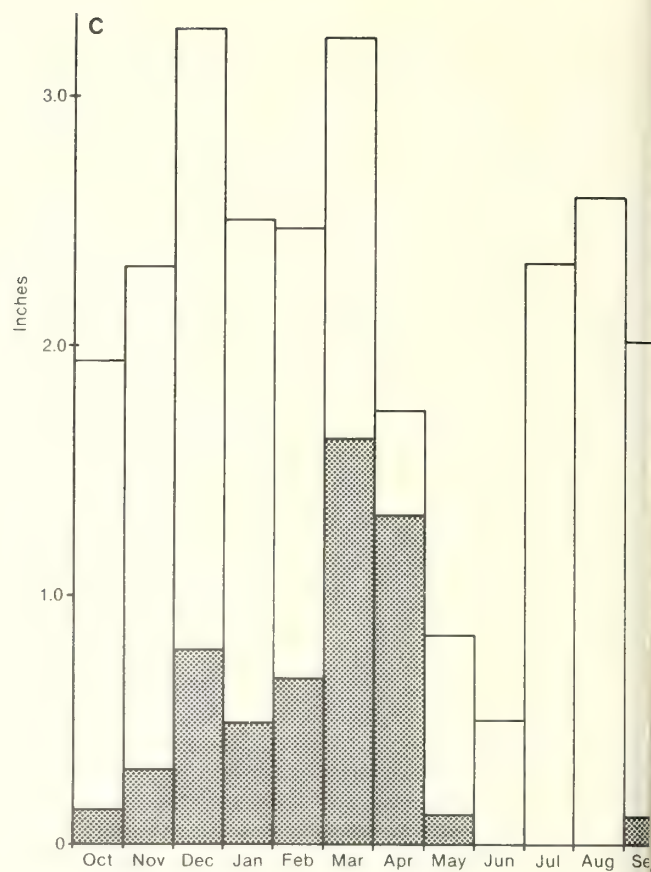
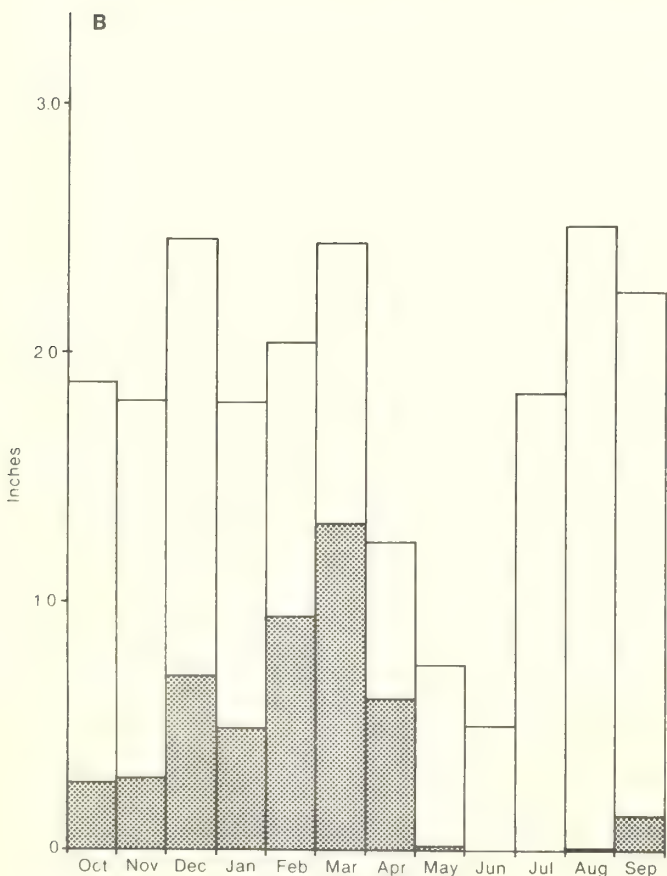
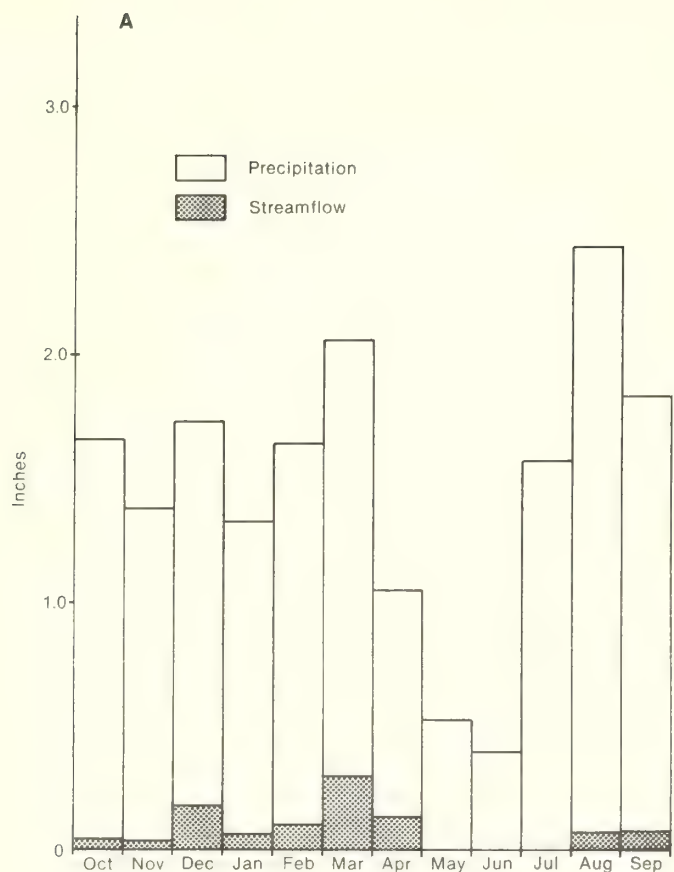


Figure 4.—Distribution of monthly precipitation and streamflow on Beaver Creek in (A) Utah juniper, (B) alligator juniper, and (C) ponderosa pine.

(ET) (table 1). There is little if any carryover effect of soil water storage from one water year to the next. Summer rains have generally ceased by early or mid-September and the soil profile has begun to dry by the beginning of the new water year. Streamgages on Beaver Creek are sealed to relatively impervious bedrock and significant leakage is not evident.

Differences in the average ET index between vegetation types (table 1) reflect differences in precipitation and temperature with elevation and in timber basal area.

This is a simplistic approach for obtaining an estimated index of ET, but it can be used successfully on Beaver Creek because of the lack of significant loss of precipitation to deep seepage. One major factor influencing water yield from these areas is the distribution of precipitation. Only winter precipitation has a significant chance of contributing to streamflow. If more of the annual precipitation were produced in the summer season, proportionately less streamflow would probably be produced.

Generally, streamflow is directly related to precipitation. However, during some years this relationship

anged as a result of anomalies in the distribution of precipitation. For example, in 1970 nearly average annual precipitation produced below average water yield because of low precipitation from December through February. Mean annual water yields and ranges for the three vegetation types on Beaver Creek are shown in table 1 and figure 5.

All watersheds in the three vegetation types lie on lava flow surfaces that yield a maximum of stormflow and a minimum of deep seepage.³ Each lava flow has the distinct set of vertical contraction joints that do not penetrate from one flow to the next. Investigations suggest that these contraction joints are not conducive to transporting large volumes of water to the subsurface. The water producing characteristics for the Mogollon Rim have been summarized by Feth and Hem (1963). They estimate that 98% of the precipitation that falls on the Mogollon slope leaves the region as streamflow, evaporation, and transpiration.

The lava bedrock that covers the Beaver Creek watershed is relatively impervious and prevents water to take except in fractured zones that extend to the sedimentary rock below. Evidence suggests that most of the experimental watersheds on Beaver Creek are dry, with only 2 out of 20 basins or 6% of the study area having any indication of water loss through deep seepage. This supports the previously mentioned conclusions of ground water investigators who estimate that only 2% of the precipitation that falls on the Mogollon Slope reaches the sedimentary aquifers below the lava cover.

Precipitation

Annual Precipitation.—Annual precipitation mean and range for the three vegetation types on Beaver Creek are presented in figure 5. These values reflect changes in elevation across the Mogollan Rim. Snow-

fall accounts for 18, 27, and 37% of the annual precipitation in the Utah and alligator juniper and pine types, respectively.

Seasonal Distribution.—August has the greatest amount of precipitation in both juniper types (fig. 4). In the pine zone, December and March have the most precipitation followed by August. May and June typically have the least precipitation in all three vegetation types.

Winter precipitation is normally associated with frontal storms. Winter averages are presented in table 1 and shows the increase in precipitation amount with elevation from the Utah juniper to the pine type. Snowfall commonly begins in November and increases into December. Usually snowfall declines in January and February followed by an increase to a peak in March.

Average peak water equivalent of the snowpack in the pine type near Beaver Creek is 4.0 inches (10.2 cm). This average is based on 30 years of data from the Soil Conservation Service snow courses at Mormon Lake, Mormon Mountain, Happy Jack, and Newman Park (U.S. Department of Agriculture 1975). The snow regimes on Beaver Creek are characteristic of these and other locations along the Mogollon Rim. Typically the snowpack is intermittent in the juniper types while a continual snowpack is common in the pine.

Nearly all summer precipitation occurs as thunderstorms and, although they occur frequently, individual storms usually cover relatively small areas. Mean summer rainfall is similar in the three vegetation zones with an average of 7.0 and 8.0 inches (17.8 and 20.3 cm) in the two juniper types and 8.5 inches (21.6 cm) in the pine (table 1). Summer rains generally begin in July and reach their peak in August (fig. 4).

Annual Precipitation Frequencies.—Probability distributions of annual precipitation in the three vegetation types were determined and using the 25th and 75th percentiles to define extreme events, annual pre-

Table 1. Annual and seasonal precipitation, water yield, and evapotranspiration for three vegetation types on Beaver Creek

	Utah juniper ¹			Alligator juniper ²			Ponderosa pine ³		
	Mean	Standard deviation	Coefficient of variation	Mean	Standard deviation	Coefficient of variation	Mean	Standard deviation	Coefficient of variation
	— inches —		percent	— inches —		percent	— inches —		percent
Precipitation									
Winter	11.01	4.50	41	12.74	5.40	42	16.97	6.79	40
Summer	7.02	2.30	33	7.97	2.19	28	8.53	2.67	31
Annual	18.03	4.14	23	20.71	5.03	24	25.50	6.54	26
Water Yield									
Winter	0.90	1.48	164	4.61	5.27	114	5.42	4.94	91
Summer	0.16	0.38	238	0.16	0.46	288	0.14	0.44	314
Annual	1.06	1.44	136	4.77	5.22	109	5.56	4.87	88
Evapotranspiration									
Annual	16.97	3.13	18	15.94	2.88	18	19.94	3.30	17

¹49 station years of data

²48 station years of data

³154 station years of data

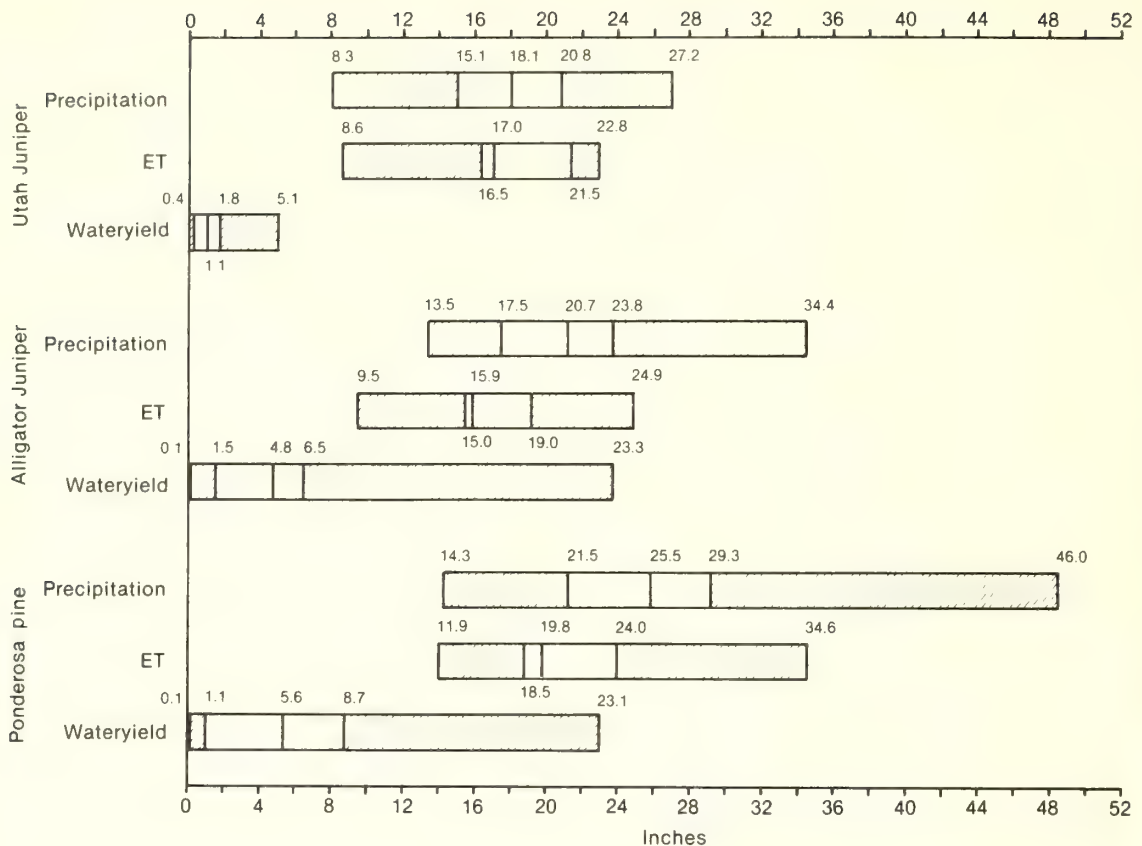


Figure 5.—Mean annual precipitation, evapotranspiration, and water yield and their ranges by vegetation type on Beaver Creek (left and right hatched area represent the 75th and 25th percentiles).

precipitation amounts in the hatched area of each bar may be considered relatively high and low, respectively (fig. 5).

Evapotranspiration

Annual Evapotranspiration.—In the Utah juniper types with a mean annual precipitation of 18.0 inches (45.7 cm), there is a mean annual ET of 17.0 inches (43.2 cm). In the alligator juniper, mean annual precipitation is 2.7 inches (6.9 cm) higher and ET is reduced 1.1 inches (2.8 cm). Decrease in ET is the result of 70% less timber basal area in the alligator juniper type. There is also the effect of a lower ET stress because of a 5° F (2.8° C) reduction in mean annual temperature at the higher elevation. Mean annual precipitation in the pine type is 7.5 inches (19.0 cm) higher than in the Utah juniper and has 2.9 inches (7.4 cm) additional ET. The average basal area of the pine type is 2 times that in the Utah juniper. This factor apparently outweighs the influence of the lower mean annual temperature of 10° F (5.6° C) in lowering ET stress. Annual ET ranges for the three vegetative types are illustrated in figure 5.

Annual Evapotranspiration Frequencies.—Probability distributions of annual evapotranspiration were also determined and using the 25th and 75th percentiles to define extreme events, annual evapo-

transpiration amounts in the hatched area of each bar may be considered relatively high and low, respectively (fig. 5).

Streamflow

Annual Streamflow.—Mean annual water yields have averaged 10, 37, and 33% of mean winter precipitation in the Utah juniper, alligator juniper, and pine type, respectively (table 1). Since the majority of the annual water yield on Beaver Creek comes during the winter season, mean annual runoff efficiency (ROE) is defined as the ratio of mean annual water yield to mean winter precipitation.

ROE on all pine watersheds range from 20 to 38%. Much of this variation results from differences in mean winter precipitation that ranges from 14 to 19 inches (36 to 48 cm) and from differences in watershed topographic orientation. ROE is often greater in the alligator juniper than in the other two vegetation types. This increased ROE reflects the influence of the less dense overstory, sparser litter cover, and soil type.

Seasonal Distribution.—Seasonal distribution of streamflow on Beaver Creek follows the pattern typical of areas that are dependent upon snowmelt (fig. 4). Winter water yield accounts for 85% of the total annual streamflow in the Utah juniper and 97% in the alligator juniper and pine type (fig. 4). Winter stream-

ly, which is relatively low in October and November, increases in December. Watersheds in all three vegetation types reach their maximum water yield in March. Streamflow is essentially nonexistent in May (except where residual flow may continue from winter snowmelt), June, and July. Summer streamflow usually only occurs in August and September and is least frequent in the pine. Summer flow generally terminates by early September in all three vegetation types.

May and June have the least amount of precipitation in the Utah juniper type and result in essentially zero streamflow. By August the soil water storage capacity of watersheds in this vegetation type begin to diminish as a result of the summer rains and streamflow may be initiated. There is streamflow about 2 years out of 10 from August through January and about 1 year out of 10 in February and March, the most favorable months for streamflow in the Utah juniper type.

Winter precipitation in the Utah juniper type comes either rain or snow. The snow generally melts rapidly because the lowest mean monthly temperature is in January at 38° F (3.3° C). Soil water storage approaches capacity in the early winter period and evaporation rates are low. Water percolating through the shallow soil mantle soon reaches bedrock and becomes increasingly more available for streamflow. The watersheds, therefore, are considered primed for the spring snowmelt season.

Spring snowmelt in the juniper types is during February, March, and April. Because nearly the whole watershed is often charged, streamflow rises rapidly to its peak in March. Water yield then drops sharply in April as the residual snowpack is depleted and stored water is reduced. Residual flow from spring snowmelt is usually terminated in March or early April.

May and June also have the least amount of precipitation in the pine type. Streamflow frequency and amount increases during the fall and winter water yield reaches an early winter high in December and remains there until March.

Spring snowmelt in the pine type is during March, April, and May. There is a sharp increase in snowmelt in March when the mean monthly temperature reaches 48° F (1.1° C); because nearly the whole watershed is charged, average streamflow rises rapidly. Water yield drops sharply in early May as the residual snowpack is depleted, leaving the major part of the watershed with zero flow.

The summer rainfall season in the pine follows the spring and early summer dry period and is during the time of highest ET demand, resulting in little flow being produced. There is streamflow in September and October 12 and 18% of the time, respectively. This indicates that most summer precipitation in the pine type is used to recharge soil water storage and to provide water for ET.

Annual Streamflow Frequencies.—Again using the 25th and 75th percentile from probability distributions of annual streamflow to define extreme events, annual streamflow amounts in the hatched area may be considered relatively high and low events, respectively (fig. 5).

Annual Peak Discharge.—Average annual peak discharge in the Utah juniper is $117 \text{ ft}^3 \cdot \text{s}^{-1} \cdot \text{mi}^{-2}$ ($1.3 \text{ m}^3 \cdot \text{s}^{-1} \cdot \text{km}^{-2}$), 112 $\text{ft}^3 \cdot \text{s}^{-1} \cdot \text{mi}^{-2}$ ($1.2 \text{ m}^3 \cdot \text{s}^{-1} \cdot \text{km}^{-2}$) in the alligator juniper, and 90 $\text{ft}^3 \cdot \text{s}^{-1} \cdot \text{mi}^{-2}$ ($1.0 \text{ m}^3 \cdot \text{s}^{-1} \cdot \text{km}^{-2}$) in the pine (fig. 6). In the Utah juniper type, annual peak flows are more heavily influenced by the orographically produced rain events that have been responsible for 39% of all peak discharges. The peak discharge pattern in the alligator juniper type is similar to that in the pine type during the winter but is more heavily influenced (31% of the peak discharge) by summer thunderstorms. In the pine type only 11% of the annual peak discharges occurred in the summer season.

The average annual peak discharges presented above do not adequately characterize the flood hazard from these vegetation types. The average annual peak discharges are equalled or exceeded only 25% of the time in the Utah juniper and 30% of the time in the alligator juniper and pine type. The median peak discharge is 32 $\text{ft}^3 \cdot \text{s}^{-1} \cdot \text{mi}^{-2}$ ($0.4 \text{ m}^3 \cdot \text{s}^{-1} \cdot \text{km}^{-2}$) in the Utah juniper and 74 $\text{ft}^3 \cdot \text{s}^{-1} \cdot \text{mi}^{-2}$ ($0.8 \text{ m}^3 \cdot \text{s}^{-1} \cdot \text{km}^{-2}$) and 44 $\text{ft}^3 \cdot \text{s}^{-1} \cdot \text{mi}^{-2}$ ($0.5 \text{ m}^3 \cdot \text{s}^{-1} \cdot \text{km}^{-2}$) in the alligator juniper and pine types, respectively. Using the 25th and 75th percentile to define extreme events, peak discharges in the hatched area may be considered relatively high and low events, respectively (fig. 6).

Summary and Recommendations

Winter season precipitation is important to the streamflow regimes along the Mogollon Rim because vegetation manipulation can affect the snowpack and

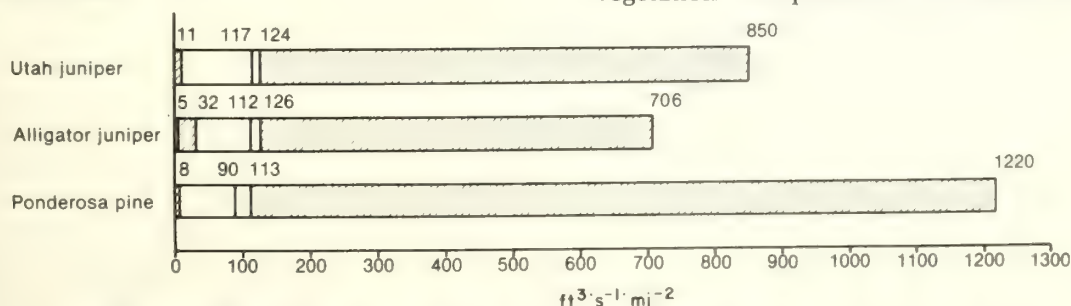


Figure 6.—Mean annual peak discharge and their range by vegetation type on Beaver Creek (left and right hatched area represent the 75th and 25th percentiles)

the evapotranspiration process and, consequently, can influence streamflow from the melting snowpack. By reducing forest densities, soil water depletion may be reduced, the snowpack may be manipulated, and consequently, more winter precipitation may be made available for streamflow. Although opportunities exist to manipulate the snowpack along the Mogollon Rim, potential mean increases in water yield are restricted by the 4.0 inch (10.2 cm) mean peak water equivalent in the pine type.

Summer precipitation in the forest types along the Mogollon Rim occurs after a 2 month dry period, at a time of high evaporation stress, and high moisture demand by vegetation. This creates a high demand upon available soil water. Nearly all summer precipitation occurs as thunderstorms and although frequent, individual storms cover relatively small areas. These small storm events generally produce no significant summer water yield or flooding even from storms with recurrence intervals of 25 and 50 years.

Mean annual water yield consists of 10, 37, and 33% of the mean winter precipitation in the Utah juniper, alligator juniper, and pine types on volcanic-derived soils, respectively. The inherent low water yield in the Utah juniper limits this vegetation type for considerations of significantly increasing water yields. The existing vegetation or its replacement is often capable of utilizing the available water supply. The relatively high soil water deficit, the seasonal precipitation pattern, and typical ephemeral snowpack conditions are not conducive to management manipulation. In contrast the naturally relatively high water yield from the alligator juniper type and its characteristic low vegetation density limits it from vegetation manipulation alternatives for the purpose of increasing water yields.

Water yield from the ponderosa pine type has been shown to be responsive to vegetation management alternatives (Brown et al. 1974).

Average annual peak discharges of 117 and 112 $\text{ft}^3 \cdot \text{s}^{-1} \cdot \text{mi}^{-2}$ (1.3 and $1.2 \text{ m}^3 \cdot \text{s}^{-1} \cdot \text{km}^{-2}$) are characteristically higher in the Utah and alligator juniper types, respectively, than the 90 $\text{ft}^3 \cdot \text{s}^{-1} \cdot \text{mi}^{-2}$ ($1.0 \text{ m}^3 \cdot \text{s}^{-1} \cdot \text{km}^{-2}$) in the ponderosa pine because of their characteristic soil type, vegetation density, and sparse litter cover. Peak discharges also are more frequent in the summer season in the juniper types.

Average annual peak discharges do not adequately characterize the flood hazard from these vegetation types because a few large flood events have skewed the distributions of the annual peak flows. Median discharges in the Utah and alligator and pine types, respectively, are 32, 74, and 44 $\text{ft}^3 \cdot \text{s}^{-1} \cdot \text{mi}^{-2}$ (0.4 , 0.8 , and $0.5 \text{ m}^3 \cdot \text{s}^{-1} \cdot \text{km}^{-2}$).

These baseline data from three vegetation types on Beaver Creek can be used to evaluate the potential water yields of vegetation manipulation. These data also provide an understanding of the upland hydrology of naturally vegetated watersheds on volcanic-derived soils along the Mogollon Rim in north-central Arizona.

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Baker, Jr., Malchus B. 1981. Hydrologic regimes of forested areas in the Beaver Creek watershed. USDA Forest Service General Technical Report RM-90, 8 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

The hydrologic regimes of watersheds in the Utah and alligator juniper woodland and ponderosa pine forest type along the Mogollon Rim in north-central Arizona are described. Baseline data describe precipitation, evapotranspiration, and streamflow processes in untreated watersheds on volcanic-derived soils.

Keywords: Forest hydrology, woodland hydrology, water yield management, *Pinus ponderosa*, *Juniperus* spp.

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Mountains



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Forest Service

Rocky Mountain Forest and Range Experiment Station

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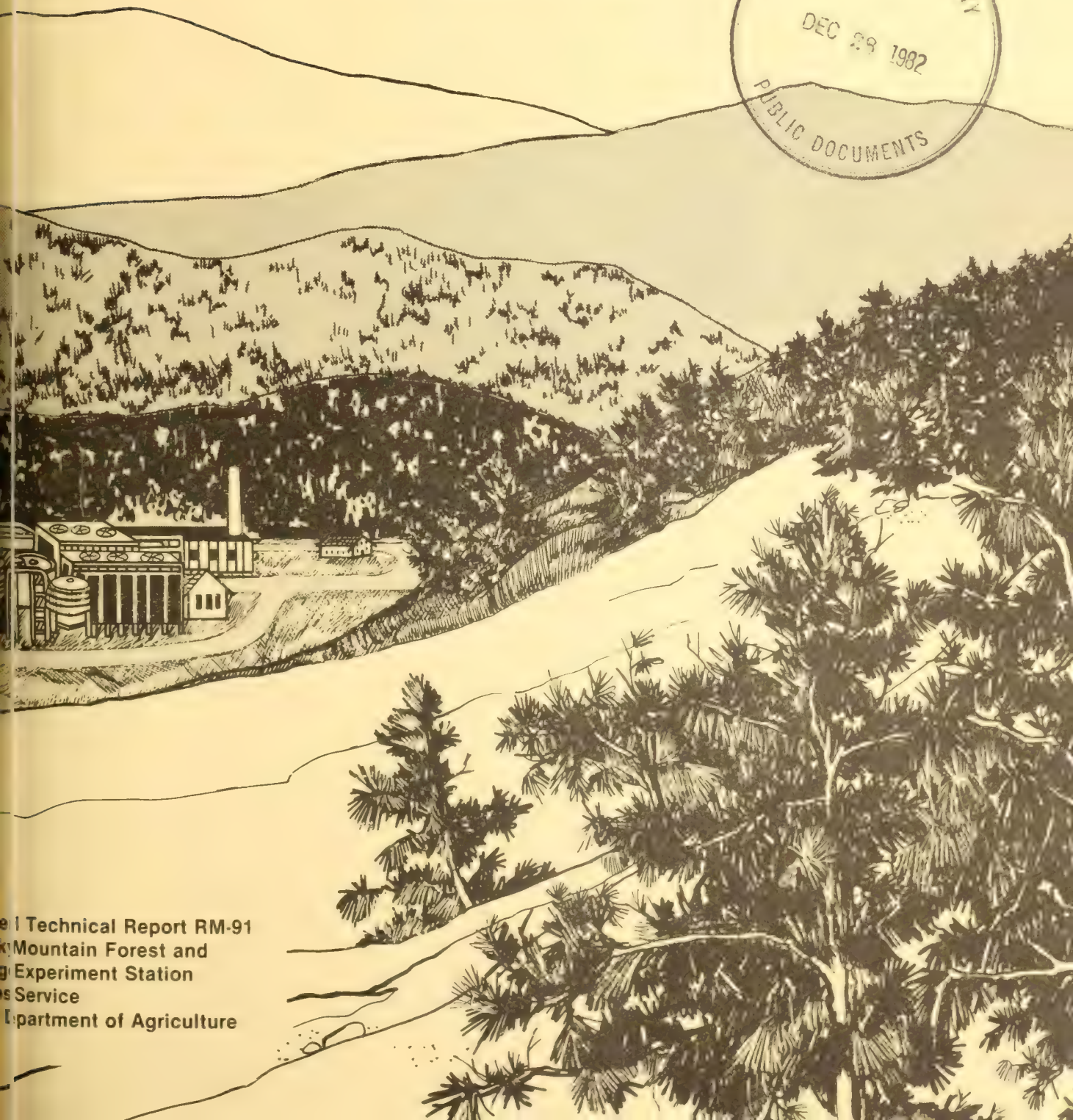
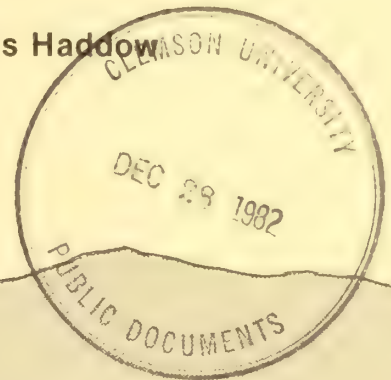
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Air Quality, Oil Shale, and Wilderness – A Workshop to Identify and Protect Air Quality Related Values of the Flat Tops

January 13-15, 1981
Glenwood Springs, Colorado

Douglas G. Fox, Dennis J. Murphy, and Dennis Haddock
Technical Coordinators



Forest Technical Report RM-91
Rocky Mountain Forest and
Experiment Station
Forest Service
Department of Agriculture

Abstract

In January 1981, a workshop was conducted to discuss the potential impacts of oil shale developments on the air quality of western Colorado. Participants of the workshop included nationally recognized specialists in air quality modeling, in visibility, and in effects of air pollution on soil and water, fish and wildlife, and vegetation. The five working group reports that resulted outline an ambitious program of research necessary in order to protect the Flat Tops Wilderness. The workshop illustrates a general approach to the problem of identifying air quality related values. It is anticipated that this approach will prove useful to all federal land managers involved with Class I area protection.

**Air Quality, Oil Shale, and Wilderness —
A Workshop to Identify and Protect
Air Quality Related Values of the Flat Tops**

Douglas G. Fox,¹ Dennis J. Murphy,¹ and Dennis Haddow²

Technical Coordinators

Jointly sponsored by
U.S. Forest Service, Rocky Mountain Region
White River National Forest
Rocky Mountain Forest and Range Experiment Station

¹USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, in cooperation with Colorado State University.

²USDA Forest Service, Rocky Mountain Region (Region 2), Lakewood, Colorado.

PREFACE

The 1977 Amendments to the Clean Air Act established a new air quality program charged with maintaining clean air in those parts of the country where the air is currently cleaner than that required to protect public health. This Prevention of Significant Deterioration (PSD) program established Class I areas and gave the federal land manager a primary role in reviewing new pollution sources to ensure that "air quality related values" (AQRV's) are not adversely impacted.

There is considerable uncertainty associated with determining precisely what constitutes an adverse impact on air quality values. It is clear from the Act, supporting regulations, and USDA Forest Service policy (FSM 2120) that AQRV's include, but are not limited to, visibility, flora, fauna, soil, water, and cultural characteristics of the Class I area. It is not clear what level of effect upon these values is to be judged adverse. At the present time, the Forest Service, both nationally and in the Rocky Mountain Region (Region 2), has no policy dealing with either the level at which an effect is adverse or the procedure by which a judgement on adversity should be made. As of September 1981, no adverse impact has ever been determined for any AQRV within any Forest Service-administered Class I area. It is, however, unlikely that this will continue indefinitely. There is a need to develop procedures that will allow rational evaluation of effects on AQRV's.

The Flat Tops Wilderness, located on the White River and Routt National Forests, is such a Class I area, and the Forest Service, therefore, must evaluate permits for new pollution sources relative to their potential impact on the area. Of the 88 Forest Service-administered, mandatory Class I areas throughout the United States, none is more likely to experience impacts than the Flat Tops. Coal mining and power generating facilities, increased mineral (uranium and others) activity, and the rapid upsurge in oil shale processing facilities have all been proposed essentially upwind and within a 50-mile radius of the Flat Tops.

The Forest Meteorology and Air Quality Unit of the Rocky Mountain Forest and Range Experiment Station is engaged in research to help develop tools and procedures to aid decisionmaking related to PSD permitting. A critical step in this decisionmaking involves the identification of, and evaluation of potential impacts upon wilderness AQRV's. At the same time, Region 2 of the Forest Service is facing similar operational needs associated most specifically with the Flat Tops Wilderness and oil shale development. For these reasons the Forest Service convened a workshop at Glenwood Springs, Colo., during January 1981. The participants included nationally recognized experts in air quality impacts on vegetation, fish and wildlife, water, and visibility, and specialists in each of these subjects from the Regional Office, the White River and the Routt National Forest staffs. The objective of the workshop was to identify those elements of the Flat Tops ecosystem most likely to experience any impact as a result of projected pollution increases. Secondly, having identified these most sensitive elements, the participants were asked to determine the extent of available information and to design studies to gather any data needed to evaluate the potential impact on the Flat Tops.

The outcome of this workshop should be of broad national interest for two reasons: It represents a first step in the PSD permitting process, illustrating one procedure through which AQRV's can be identified; and it provides an indication of the scientific magnitude of the task mandated to federal land managers by the Clean Air Act 1977 amendments. In addition, it should provide a preliminary indication for interested parties of the Flat Tops AQRV's.

This report summarizes the findings of the workshop. Major recommendations and conclusions are outlined in an executive summary. A brief overview of intended oil shale development and an outline of the Forest Service responsibilities follows. Finally, group reports are included to provide the backup information for the recommendations.

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Air Quality, Oil Shale, and Wilderness – A Workshop to Identify and Protect Air Quality Related Values of the Flat Tops

Douglas G. Fox, Dennis J. Murphy, and Dennis Haddow
Technical Coordinators

INTRODUCTION

Oil shale projects lead the proposed development of energy resources in western Colorado. Figure 1 locates a group of proposed projects in relation to the Flat Tops Wilderness area (a mandatory Class I area administered by the USDA Forest Service). Since all of the Colorado developments are located within 100 km of the Flat Tops, they will each require a Prevention of Significant Deterioration (PSD) review of their impacts on the AQRV's of the Flat Tops. Table 1 provides a key to figure 1 and a listing of some of the projected developments. Table 2 shows the projected 1982 levels of emissions and the 1985 projections for some regulated pollutants. The various processes represent combinations of

aboveground retorting and in situ combustion to drive off the oil from the shale thermally. Each process has somewhat different emission characteristics. For the purposes of this workshop, it is sufficient to consider the emission figures shown in table 2. Actual numbers will be different as specific processes develop.

In addition to the increase in emissions, the industrial development will lead to major influxes of people. Figure 2 illustrates one projection of population increase associated with the oil shale development.

The Forest Service, as the federal land manager for the Flat Tops Wilderness, has "an affirmative responsibility to protect air quality related

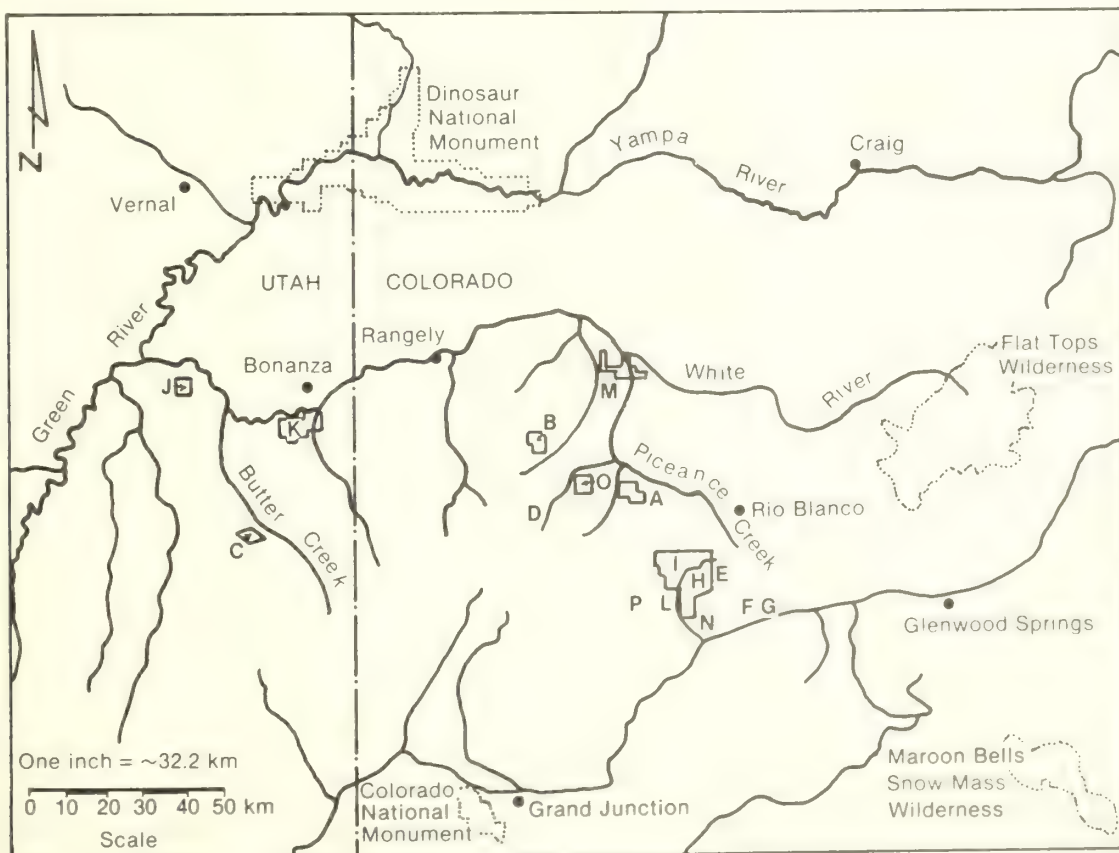


Figure 1.--Locations of proposed oil shale developments in Colorado and Utah.

Table 1.--Proposed oil shale development projects in Colorado and Utah¹

Oil shale project Lease site (Operators)	Location ²	Process	Production rate			
			1982	1985	1990	1995
----- (barrels/day) -----						
Cathedral Bluffs Oil Shale Co. Lease Tract C-b (Occidentals, Tenneco)	A	38% Lurgi 62% MIS	--	30,000	100,000	100,000
Project Rio Blanco Lease Tract C-a Gulf, Standard (Indiana)	B	100% Lurgi	--	45,600	76,000	135,000
Geokinetics, Inc. Uinta Basin	C	Occidental MIS	5,000	15,000	50,000	50,000
Equity Oil Naval Oil Shale Reserve	D	Bx in-situ	--	--	--	--
Piceance Basin	E	Paraho	--	--	28,000	50,000
Union Oil/Long Ridge Piceance Basin	H	Union B	9,500	30,000	50,000	100,000
Colony/Tosco Parachute Creek Piceance Basin (Exxon, Tosco)	I	Tosco/Colony/Sand Wash	--	38,400	46,200	46,200
Tosco Sand Wash Uinta Basin	J	Tosco/Colony/Sand Wash	--	23,100	46,200	46,200
White River Project Lease site U-a, U-b (Phillips, Sohio, Sunoco)	K	Paraho	--	--	--	90,000
Chevron Oil Piceance Basin	L	Union B	--	15,600	66,600	100,000
Superior Oil Piceance Basin	M	Superior	--	6,700	12,000	12,000
Mobil Oil Piceance Basin	N	Union B	--	--	50,000	91,500
Carter Oil Piceance Basin	O	Union B	--	--	60,000	60,000
Cities Service	P	--	--	--	--	--
Total			14,500	204,400	585,000	880,900

¹Source: Anderson, G. E., J. R. Doyle, D. A. Latimer, C. S. Liu, M. A. Wojcik, and J. A. Johnson. 1981. Air quality impacts of anticipated development in oil shale operations in western Colorado and eastern Utah. April 2, 1981. Report by Systems Application, Inc., San Rafael, Calif.

²Codes match with those of figure 1.

Table 2.--Projected oil shale processing emission rates
in 1982 and 1985

Oil shale project	Location ¹	Process	Production capacity	Average emission rate (g/s)				
				SO ₂	NO _x	HC	TSP	CO
1982								
Geokinetics, Inc. Uinta Basin	C	Occidental (MIS)	5,000	3.1	15.4	0.7	4.1	6.1
Union Oil Piceance Basin	H	Union (Union B)	9,500	14.6	18.3	16.8	5.0	11.3
Total			14,500	17.7	33.7	17.5	9.1	17.4
1985								
Occidental Oil Tract C-b	A	Occidental (MIS)	30,000	18.2	92.5	3.9	24.6	30.7
Project Rio Blanco Track C-a	B	Rio Blanco	45,600	12.9	106.4	5.0	35.8	48.1
Geokinetics, Inc. Uinta Basin	C	Occidental (MIS)	15,000	9.1	46.2	2.0	12.3	18.4
Union Oil Piceance Basin	H	Union (Long Ridge)	30,000	46.1	57.7	52.9	15.9	35.8
Colony/TOSCO Parachute Creek	I	TOSCO II	38,400	31.7	216.8	38.9	59.1	7.0
TOSCO Uinta Basin	J	TOSCO II	23,100	19.1	130.4	23.4	35.6	4.2
Chevron Oil Piceance Basin	L	Union (Long Ridge)	15,600	24.0	30.0	27.5	8.3	18.6
Superior Oil	M	Superior	6,700	24.4	12.1	1.9	5.3	3.3
Total			204,400	185.5	692.1	155.5	196.9	172.1

¹Codes match with those of figure 1.

values" of the area. This responsibility manifests itself through participation in the permit application and review process. For areas such as western Colorado, PSD provisions require that nowhere shall the Class II increments for sulfur dioxide (SO₂) and total suspended particulates (TSP) be exceeded; that best available control technology (BACT) applies; and that, in cooperation with the federal land manager, the Class I area (Flat Tops Wilderness) shall be protected from any adverse impact. This responsibility,

while specifically identified by the Clean Air Act, is really not substantially different from the responsibilities granted under the Wilderness Act and the establishment legislation for most wilderness areas. The additional responsibility granted by the Clean Air Act merely provides authority to act and exert influences more directly.

The Environmental Protection Agency (EPA) and state regulatory agencies have technical

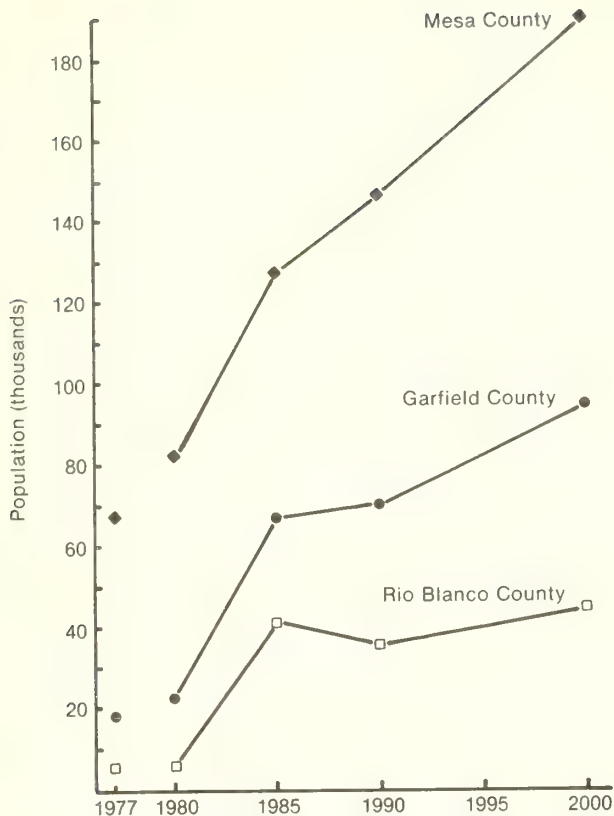


Figure 2.--Projected growth of counties in north-western Colorado from oil shale development, 1980-2000.

1977--actual population from special U.S. census

1980-2000--projections assume oil shale development with a production level of 500,000 bpd by 1990 and 750,000 bpd by 1995 combined with other energy industry (e.g., coal, electric generation, oil, and gas) expansion

Source: Office of Technology Assessment (1980)

responsibilities for tasks such as tracking the consumption of the numerical increments and negotiating best available control technology. The federal land manager must evaluate biological and social impacts and determine if they are adverse or not. It is consistent with wilderness management responsibilities to protect these areas from any unauthorized human-caused impacts.

The Flat Tops Wilderness will potentially experience adverse impacts. It is, therefore, necessary to identify what the AQRV's of the Flat Tops are and at what levels of pollution the various values might experience an impact.

EXECUTIVE SUMMARY

Traditionally, regulatory agencies dealing with air quality have been responsible for

monitoring pollutants, predicting future pollutant concentrations, and requiring various engineering controls to reduce emissions and, ultimately, the atmospheric concentration of pollutants. The Clean Air Act Amendments of 1977 additionally gave the federal land manager "an affirmative responsibility to protect the air quality related values of any such lands within a Class I area." This statement gives the USDA Forest Service a responsibility to determine the biological, physical, and visibility impacts of air quality degradation in the designated Class I wilderness area for which it is responsible.

A developing oil shale industry on the western slope of Colorado has a potential to impact the AQRV's of the Flat Tops Wilderness area adversely. As a result of increased activity in the oil shale industry, the USDA Forest Service, Rocky Mountain Region, and the Rocky Mountain Forest and Range Experiment Station, along with the White River National Forest, sponsored a workshop in Glenwood Springs, Colo., January 13-15, 1981, on air quality related values in the Flat Tops Wilderness area.

The meeting brought together scientists working in the areas of pollutant effects and local field personnel in an effort to assess the potential biological, physical, and visibility effects the oil shale industry would have on the Flat Tops and to consider monitoring and research needs.

Participants were divided into groups on visibility, soil and water, fish and wildlife, vegetation, and air quality modeling. Members of each group produced a report specific to their area of expertise; however, several common recommendations emerged. It was recognized by all groups that there must be a great deal of cooperation among industry, local and state agencies, and, especially, among federal agencies in the development of oil shale and protection of wilderness values. Also, all groups strongly recommended that air quality dosage models be developed for the area. The models are needed to assess potential pollutant concentrations in various areas of the Flat Tops Wilderness so that dosages to soil, vegetation, water, fish, and wildlife can be estimated. A modeling program will also be extremely important in designing cost-effective monitoring programs for biological and physical effects in the wilderness area.

Specific group recommendations are as follows:

1. Visibility: Proposed a long-term visibility monitoring program in the wilderness to measure current conditions, and future emissions of those pollutants that have a potential to degrade visibility. Also proposed studies of wilderness users to identify their perceptions of visibility impairment and its significance to them.

2. Soil/Water: Proposed monitoring the sensitive, poorly buffered, high lakes (i.e., Surprise, Upper Island, and Shingle) for any changes

in pH and nutrients. Additionally, the group proposed a modification to the current USDA Forest Service Flat Tops water monitoring program and suggested long-term monitoring of precipitation quality, soil chemistry, and lake chemistry.

3. Fish and Wildlife: Outlined a process to aid the USDA Forest Service in better identifying sensitive receptors in the Flat Tops. Several sensitive indicator species to the expected pollutants are cutthroat trout, beaver, elk, deer, white-crowned sparrow, pika, ptarmigan, and bees. A long-term monitoring program of these species was identified.

4. Vegetation: Suggested a two-stage monitoring program. The first stage would utilize the most sensitive plant species in the wilderness to alert the federal land manager that air pollutants are reaching the wilderness in potentially significant quantities. The second stage would involve monitoring the viability of key species of the general Flat Tops ecosystem. The first-stage indicators suggested were lichen and bryophytes to monitor sulfur dioxide (SO_2) and needle retention in spruce and fir to detect significant quantities of ozone (O_3).

5. Modeling/climate: Stressed the need for further research in atmospheric dispersion in complex terrain areas and in deposition and dosage models. Since the Flat Tops Wilderness is the first high ground directly downwind from the oil shale area, pollutants released during mining and processing are likely to be deposited by both dry and wet (precipitation) mechanisms. Dosage models are needed to identify and quantify potential impacts on vegetation, soil, water, fish, and wildlife. The modeling requirements are illustrated in figure 3. Use of models in complex terrain areas will also aid in the conduct of monitoring programs by locating areas and times of greatest potential impact.

The workshop (i.e., the results from it) should be viewed as an example of how AQRV's can be identified and of the magnitude of the task that faces federal land managers in providing

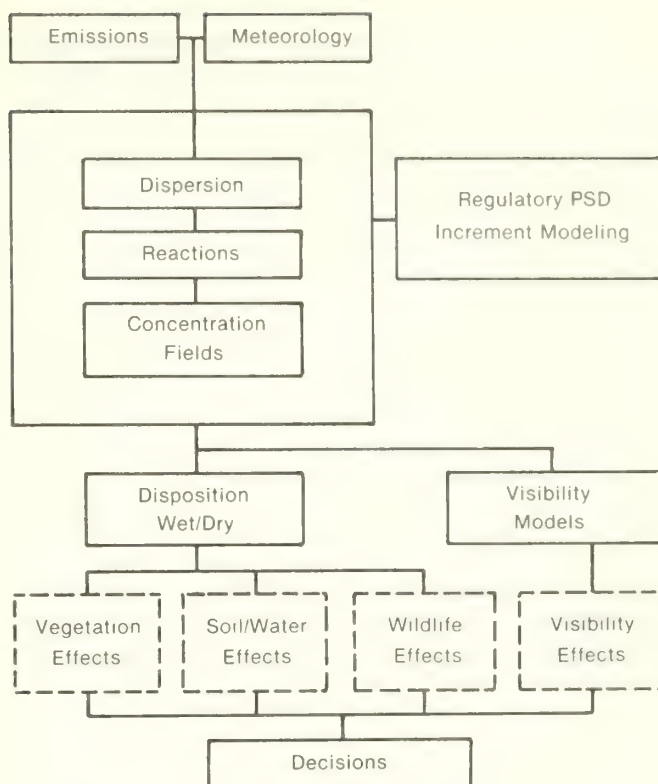


Figure 3.--Air quality modeling required to support decisions based upon AQRV determinations. (For more detail, see Group Report 5.)

protection. While the specifics apply to the Flat Tops Wilderness, the procedure is suggested as a model that can be applied to all Class I areas to accomplish the following results:

- o Public identification of the scope and the nature of AQRV's on a Class I area specific basis.
- o Direct interaction between specialists and local federal land managers.
- o Early information relating to the nature of potential inputs and a plan to address further evaluation.

GROUP REPORTS

1. VISIBILITY

W. Malm, D. Haddow, W. Herrett,
D. Latimer, E. Martin, R. Miller

INTRODUCTION

The Clean Air Act singled out visibility from air quality related values (AQRV's) and, in fact, directed the establishment of a regulatory program to provide for the achievement of, as a national goal, "The prevention of any future, and the remedying of any existing, impairment of visibility in mandatory Class I Federal areas which impairment results from manmade air pollution" (Clean Air Act, 169A(a)(1)). Subsequently, the USDA Forest Service conducted a workshop aimed at defining methodologies to quantify the value of visibility (Fox et al. 1978). The Environmental Protection Agency (1979) reported to Congress that "nearly all managers of Class I areas indicated the need to prevent existing visibility conditions from deteriorating as a result of new source impacts." Their data were taken from surveys conducted by the U.S. Departments of Agriculture and Interior. The importance of visibility to Colorado wilderness users has been indicated by a number of studies. In a recent study of the cost effectiveness of wilderness, Colorado residents stated that "viewing the scenery" was first in importance among a comprehensive list of 20 specific wilderness experiences that respondents were asked to rate from unimportant to extremely important (Walsh et al. 1982). These same respondents ranked "protecting air quality" second among 13 specific reasons for valuing wilderness.

In a continuing sequence of research studies, B. L. Driver and his colleagues have attempted to quantify the significance of various wilderness experiences to recreationists. Users of the Indian Peaks area selected "clean fresh air" as first out of 73 physical attributes that contributed to their satisfaction.³ A recent study⁴ attempted to identify (1) physical

resource attributes of wilderness "that users perceived either added to or detracted from the level of satisfaction obtained," and (2) "the psychological outcomes (immediate benefits) that users perceived either added to or detracted from the level of satisfaction obtained" for three Colorado wilderness areas, Weiminoche, Eagles Nest, and Rawah. The results support the concept that clean air is a major attribute of wilderness and that it contributes significantly to visitors' enjoyment. Physical resource attributes identified by over 250 users of these three wilderness areas were ranked, according to a numerical scale, from strongly adding to satisfaction, to most strongly detracting from satisfaction. The relative ranking of eight general groupings of these physical resource attributes was the same for all the areas, namely:

1. Water related (e.g., cascading streams, mountain springs, waterfalls).
2. Vegetation (e.g., alpine meadows, wildflowers, forests).
3. Attractive topography (e.g., steep hillsides, rock peaks, rugged terrain).
4. Large wildlife (e.g., elk, bighorn sheep).
5. Small wildlife (e.g., beaver, eagles).
6. Fish related (e.g., good fishing streams, trout).
7. Nuisance topography (e.g., rock slides, boulder fields).
8. Bad weather (e.g., hail and sleet, wind, unpredictable).

Attractive topography appears to be related to good visibility, although the connection has not been scientifically established. Psychological outcome domains were ranked on a similar basis from most strongly adding to satisfaction, to most strongly detracting from satisfaction by wilderness users. Among the general groupings, "relationships with nature" was first, and "escaping physical pressure" was second, in all three wilderness areas. Within the first category, "enjoying the scenery" and "enjoying the sights and sounds of nature" ranked either one or two among all the psychological benefits perceived by users. The numerical rankings, in fact, showed these as dramatically higher than all the others. Driver and colleagues (1979) and Loomis and Green (1979)

³Final Report: Identifying resource attributes providing opportunities for dispersed recreation. By P. J. Brown, G. E. Haas, and M. J. Manfredo, submitted to R. S. Driscoll, Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo., November 1977.

⁴Final Report: Relationships between resource attributes and psychological outcomes perceived by wilderness recreationists. An unpublished report by P. J. Brown and G. E. Haas, submitted to B. L. Driver, Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo., March 1980.

are continuing to attempt quantification of the wilderness user experience, in particular with regard to visibility. Nevertheless, it seems safe to tentatively conclude that the ability to enjoy western Colorado scenery through pure clean air is one, if not the single most, important wilderness attribute as perceived by wilderness users.

It is also important to note that, based upon opinions of users and managers alike, visibility in the Flat Tops Wilderness is presently considered to be unimpaired.

The Forest Service should consider an adverse impact on visibility to be visibility impairment resulting from sources subject to PSD permitting, which interferes with the management, protection, preservation, or enjoyment of the visitor's visual experience of the Flat Tops. This determination will be made on a case-by-case basis, taking into account the geographic extent, intensity, duration, frequency, and time of visibility impairments, and how these factors correlate with (1) times of visitor use and (2) the frequency and timing of natural conditions that reduce visibility. There are four questions that must be answered before it is possible to identify an adverse visibility impact, namely:

1. What is the current visibility environment?
2. What amount of visibility impairment is likely to be caused by proposed sources?
3. To what extent will this impairment be perceptible to users of the area?
4. To what extent will this visibility impairment affect the management and use of the area?

The first of these requires an identification of the visual attributes of the Flat Tops and monitoring of current conditions. The second requires extensive modeling of specific proposed sources and their impact on visibility of the area (Lattimer and Ireson 1980). The third may require site-specific studies of the perception of visibility by visitors to the Flat Tops (Malm et al. 1981). And the fourth requires a decision (Fox and Rosenthal 1981) based upon the evidence accumulated in the first three, as well as other factors. The major point is, simply, that existence of a plume or haze perceptible by wilderness visitors does not necessarily mean that an adverse impact on the visual experience of visitors will result. When the technical work of determining the likelihood of a perceptible plume is completed, only half the job is done. The next task of determining the significance of this plume to users of the area must be accomplished by the federal land managers.

THE FLAT TOPS VISUAL RESOURCE ATTRIBUTES

To identify the Flat Tops visual attributes that should be considered for protection, it is

necessary to identify key viewpoints and views currently enjoyed by wilderness users. It should be possible to identify a few key views that would adequately protect the important visual attributes of the entire wilderness area. Visitor use of each key viewpoint should be inventoried by time of year, time of day, and frequency (number of users). Big Marvine Peak has been initially identified as the key viewpoint most representative of the visual resources in the Flat Tops. Views from Big Marvine Peak include the Uintas, La Sal Mountains, Mt. Zirkel, Gore Range, and the Elk Mountains.

MONITORING OF VISIBILITY

To determine potential and actual visibility degradation from sources subject to PSD permitting, it is necessary to develop a visibility monitoring program in the Flat Tops. The site suggested for the visibility monitoring station is Big Marvine Peak. The visibility parameters that should be monitored include visual range and contrast reduction of key view elements. The monitoring package should include five automated camera systems recording pictures of selected targets within the Uintas, La Sals, Mt. Zirkel, Gore Range, and Elk Mountains.

In addition to the camera system, two telephotometers should be directed toward the La Sal and Uinta Mountains. The telephotometers will yield contrast data that will establish existing visibility levels as well as an approximate pollutant concentration along the two sight paths. Data from these instruments can be used to "calibrate" concurrently taken photographs so that the photos can be used to extract quantitative visibility data over a wide range of views. The cameras and telephotometers can be operated with 12-volt batteries recharged by solar panels. Monitoring stations within the wilderness will have to be operated without commercial power.

Included in the visibility monitoring package should be a remotely operated weather station. Without such data, it is impossible to determine the cause of any visibility impairment. Meteorological parameters needed are wind speed and direction, humidity, and temperature. These can be monitored easily with a remote automated weather station (RAWS) of the type used extensively for fire weather observations by the USDA Forest Service and other agencies.

It is also necessary to establish existing concentrations of the following gaseous and particulate pollutants that reduce visibility, and then to monitor them:

1. Particulates
 - a. Size distribution
 - b. Elemental analysis (e.g., sulfates, nitrates)
2. Gaseous Concentrations
 - a. Sulfur dioxide (SO_2)
 - b. Nitrogen oxides (NO_x)
 - c. Hydrocarbons
 - (1) Aldehydes
 - (2) Olefins
 - d. Ozone (O_3).

The electrical power and access requirements of this type of air pollution monitoring program make it nearly impossible to place the equipment within the wilderness area. The suggested location of this monitoring package is Burro Mountain, which lies near the west boundary of the Flat Tops. This can be accomplished by extending existing power lines approximately 1.6 km.

All monitoring should be carried out consistent with EPA's "Interim Guidance for Visibility Monitoring" (1980).

ADDITIONAL STUDIES REQUIRED

Studies of users' perceptions and experiences, specific to the Flat Tops, have been initiated.⁵ A study involving 222 Flat Tops visitors showed that "relationships with nature" proved to be the major psychological outcome contributing to users' enjoyment, while meadows and forests proved to be the major physical attributes contributing to this enjoyment. Users were not polled directly regarding visibility or its degradation. In order to tie more specifically into the significance of visibility, additional user surveys should be designed and conducted, building upon the knowledge already gained but focused directly on visual experiences.

Since the visibility regulations specifically refer to visibility impairments with regard to the visitors' use of an area, a short study should be undertaken to quantify such factors of visitor use as times, locations, and numbers of visitors, if such information is not already available. Perception, specific to the Flat Tops Wilderness, also needs to be defined for various levels of visibility impairment. This latter task can probably be best accomplished by using photographs of Flat Tops vistas with simulations of the visual effects of various levels of pollution. All of this research is aimed at quantifying the visual experiences and impacts of degraded visibility in the Flat Tops Wilderness.

⁵Psychological outcomes and physical resource attributes of the environment--the Flat Tops case. An unpublished report by P. J. Brown and G. E. Haas, submitted to B. L. Driver, Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo., June 1978.

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2. SOIL/WATER EFFECTS

J. Turk, S. Fifer, and W. Marlatt

BACKGROUND AND EXISTING DATA

Geology

The Flat Tops Wilderness is located on the White River Plateau, a relatively flat, high-lying area that has been moderately dissected by stream erosion and glacial action. The exceptionally flat appearance is supported largely by tertiary age basalt flows, which are relatively resistant to erosion. Fluvial and glacial dissection have in places exposed underlying sedimentary formations of Mesozoic and Paleozoic age. Where this dissection has cut through the basalt into the softer sedimentary rocks below, erosion has progressed at a more rapid rate, creating the steep canyons characteristic of this area.

The watersheds in the north and eastern sections of the wilderness have a larger proportion of "soft" sedimentary formations (Brown's Park, Maroon, Evaporites) throughout their sides and bottoms than those in the west and, consequently, are more readily erodible. The western watersheds, comprised mainly of the South Fork White River and its tributaries, have more limestone and basalt and are relatively more erosion-resistant.

Climate

Climatic conditions are typical of middle-latitude, high-elevation areas, characterized by warm summers and cold winters. Temperatures have a broad seasonal and daily variation because of a wide range of elevations and exposure. The mean annual temperature at Meeker (elevation 1,935 m) is 6.6° C, with extremes of -41° to 39.4° C. Forty kilometers east of Meeker the mean annual temperature at the Marvine Ranch (elevation 2,380 m) drops to 2.7° C.

Annual precipitation varies from 31.7 cm at Meeker to over 88.9 cm in the high-elevation areas of the Flat Tops Wilderness. Seasonal distribution of precipitation at the lower elevations is fairly uniform during the year. About 40% of the precipitation comes as snow during the December-April period. At higher elevations, snowfall accounts for approximately 70% of the annual precipitation. This accumulation of winter snow is the principal source of streamflow. Summer rainfall generally takes the form of showers that contribute little to overall water supplies. The summer precipitation is highly variable, coming from large, moist air masses and short-duration, high-intensity thunderstorms.

The combination of low temperature and great topographic relief makes the water resources of this area especially susceptible to atmospheric emissions. Prevailing wind components from the southwest and north will move air masses from oil shale development and coal-fired power plants in the Yampa Valley across the Flat Tops Wilderness area. The orographic effect of the Flat Tops is the first barrier to these air masses and should result in deposition of emissions before extensive dispersion has occurred. Additionally, the low temperatures promote the accumulation of a snowpack that is released in a short period of time, which minimizes reactions with soil and bedrock.

Streams

The Flat Tops Wilderness serves as an important water supply for the entire White River Basin. Each year more than 51,000 m³ of water is generated from the wilderness area. The water comes principally from the melting snowpacks on the high mountains, augmented to a small degree by summer precipitation. Streamflow is highly dependent on the annual spring runoff, when temperatures are high enough to melt the snowpack. The streams reach a peak flow during June, when as much as 40% of the total annual water yield is derived. Over 75% of the water is derived during May through August. Streamflows are at a minimum during November through March, when most of the water is derived from ground water sources. Figure 4 shows the runoff distribution of the South Fork of White River, which is typical of streamflows within this wilderness area.

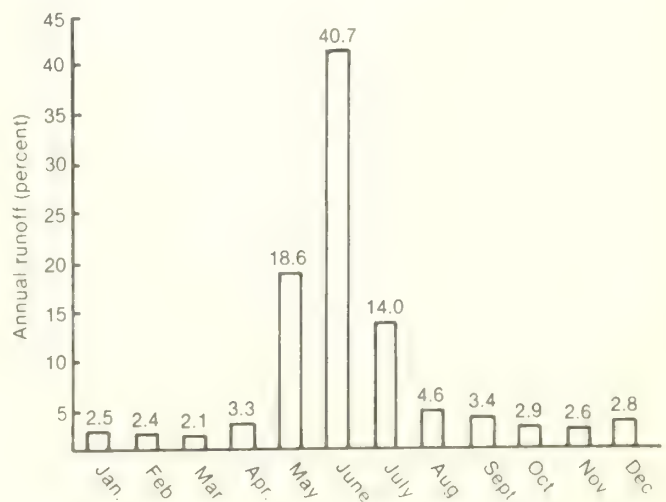


Figure 4.--Mean annual runoff distribution White River near Budges Resort, Colorado.

Water yield per unit area increases with elevation. In the alpine zone, where the ground cover is essentially rock, the annual runoff is extremely high, averaging 88.9 cm. At lower elevations, between 2,700 and 3,000 m, water yields drop to 45.7 cm. This relationship occurs primarily because of increased precipitation at higher elevations and a decrease in water consumed by vegetation.

Water Quality

Water quality information from within the Flat Tops Wilderness is available from a number of sources. Studies have been, or are currently being conducted, by the USDA Forest Service, U.S. Geological Survey, and the U.S. Bureau of Reclamation. The longest, continuous, water quality records from this area are maintained by the U.S. Bureau of Reclamation. Beginning in 1962, total dissolved solids (tds) and streamflows, recorded in cubic feet per second (cfs), were measured on the North and South Forks of the White River near the town of Buford. The total dissolved solids measurements reflect the chemical quality of the stream. They indicate the presence of carbonates, bicarbonates, chlorides, sulfates, or phosphates. The U.S. Geological Survey maintains seven streamflow measuring sites in Colorado near the Flat Tops Wilderness: Marvine Creek near Buford, North Fork White River at Buford, South Fork White River at Buford, South Fork White River at Budges Resort, Wagonwheel Creek at Budges Resort, South Fork White River near Budges Resort, and the South Fork White River near Buford. Currently, the U.S. Geological Survey is monitoring specific conductance and temperature at the seven discharge monitoring sites. Specific conductance, like total dissolved solids, is an indicator of stream salinity.

The USDA Forest Service maintains 11 sampling stations in, or adjacent to, the Flat Tops Wilderness; data collection was initiated in 1978. The parameters monitored include suspended sediment, turbidity, temperature, conductivity, dissolved oxygen, pH, alkalinity, total hardness, calcium hardness, and stream discharge. The monitoring objectives of these stations are to define present water quality conditions and to provide information useful in the interpretation of the effects of future management activities.

In general, the water quality of the streams and tributaries within the wilderness is of very good quality. The measured parameters are within the standards established by the State of Colorado for recreation, cold-water fisheries, and irrigation uses. Dissolved oxygen and pH remained relatively constant through the summer, while temperature, suspended sediment, alkalinity, hardness, and specific conductivity showed seasonal trends and varied with streamflows. A summary of water quality data collected at the USDA Forest Service sampling sites is available from the White River National Forest.

The streams were well oxygenated throughout the summer. Dissolved oxygen concentrations

varied between 6 and 11 mg/l. The concentrations remained high at lower streamflows because of cold-stream temperatures and good aeration from the turbulent flows of these streams.

Variations in alkalinity, hardness, and specific conductivity measurements were caused by the "diluting effect" of the early-season spring runoff. During the spring high-flow period, most of the runoff comes directly from high-quality snowmelt, which is very low in carbonates, bicarbonates, and dissolved solid concentrations. Consequently, concentrations of these in receiving streams are diluted, resulting in lower alkalinity and conductivity measurements. Later in the season, when streams are less dependent on the snowmelt runoff, the concentration of dissolved solids increases and the measurements are higher.

Consistently higher conductivity measurements were recorded in the Sweetwater and Marvine Creek watersheds (290-300 $\mu\text{mhos/cm}$). Lower values were observed in the South Fork White River and its tributaries (150-240 $\mu\text{mhos/cm}$). This difference, although slight, is attributed to the geologic difference between the watersheds. The Marvine and Sweetwater Creek watersheds have a significant number of "soft" sedimentary formations (Browns Park, Maroon, Evaporites). This material is more readily eroded and contains more water-soluble minerals than the limestone and basalt found throughout the South Fork White River.

The suspended sediment and turbidity measurements were highest during spring runoff, but they remained relatively low throughout the sampling period. The highest measurements were found in the Marvine, Sweetwater, and Ripple Creek watersheds. As with conductivity, the higher values are attributed to the presence of "soft" sedimentary formations in the watersheds. The lower values observed in the South Fork White River result from the predominance of erosion-resistant rock (basalt, limestone) in the watershed.

The alkalinity values indicate the streams have a relatively good buffering capacity. This means the pH of the stream systems will not be changed greatly by the addition of moderate quantities of acid (such as might be caused by oil shale development). The alkalinity is primarily attributable to the presence in the water of carbonates (CO_3) and bicarbonates (HCO_3), deriving from the atmosphere (CO_2) and the limestone (CaCO_3) and other sedimentary rocks in the watershed.

Precipitation

Snow surveys have been conducted by the USDA Soil Conservation Service in the headwaters of the North and South Fork White Rivers since 1936. Total snow depth and snowpack water content are measured each month, February through May. These measurements help forecast available water supplies for the coming year. Snow course records for 1936-1972 are available from the Soil Conservation Service.

Daily precipitation data are available from stations located at the Marvine Ranch, Meeker, Maybell, and Douglas Pass. Precipitation quality data were collected at the Maybell and Douglas Pass sites starting in 1980; data measured include major ions, major nutrients, pH, and specific conductance. The length of record is insufficient for definitive characterization of precipitation quality. However, values of specific conductance of about 4 $\mu\text{mho/cm}$ with pH values less than 6 indicate that minor additions of dissolved solids could markedly change the chemical character of the precipitation.

Lakes

A reconnaissance of 15 lakes was made by the U.S. Geological Survey in July-September 1980. Data from this study include profiles of temperature, specific conductance, major ions, nitrogen and phosphorus speciation, heavy metals, alkalinity titration curves, and lake volume.

The data indicate a wide range of chemical and biological characteristics among the lakes studied. Alkalinity, a measure of the buffering capacity towards acidification, ranges from about 5 to 70 mg of CaCO_3 per liter. Lakes with the smaller alkalinity values are located above the canyon rims on the basalt caprock. The more highly buffered lakes are in the stream valleys, and they probably receive a greater component of ground water from glacial deposits and fractured basalt than do those on the caprock itself. The lowest levels of alkalinity reflect dilution of added acid rather than neutralization by reaction with bicarbonate. The low levels of alkalinity in lakes such as Upper Island, Shingle, and Surprise make them susceptible to decreased pH from even small amounts of added acid.

Dissolved oxygen, necessary to support all higher forms of life, was found to vary from supersaturation to complete absence below the thermocline in some lakes. The addition of critical nutrients, which would increase productivity, could accelerate oxygen depletion during the period of snow cover.

Soils

Fairly detailed soil surveys have been completed for much of the western and northern portions of the Flat Tops Wilderness area (all of Rio Blanco County) (Order 3 level). Three soil mapping units are identified:

1. Dark-colored soils on the cold, forested mountain slopes.--Most of these soils are at elevations between 2,400 and 2,850 m. Parent rocks are principally sandstone, shale, quartzite, and basalt. Underlying parent materials are permeable and often calcareous.

These soils have dark-colored, moderately thick, granular A_1 horizons and light-colored A_2 horizons which tongue into blocky, clayey, low-permeability subsoils. Bedrock is usually more than 1.2 m under the surface.

Surface soils are loam to sandy loam and are generally high in organic matter. Near neutral pH exists. Little erosion is noted.

2. Light-colored soils on the cold, forested mountain slopes.--These soils are found at elevations of 2,400 to 3,300 m (particularly 2,700 to 3,000 m) on slopes that are generally steeper than those of the dark soils. Parent materials are mostly reworked granite, sandstone, shale, and basalt. Glacial, colluvial, and alluvial deposits are common along lower slopes and drainage ways.

These soils are generally loamy, low in organic material, and have very thin or no A_1 horizons. The A_2 horizons are light-colored, moderately thick, and slightly acidic. Subsoils are generally quite deep and permeable and range in texture from sandy loam to clay.

3. Shallow and deep, dark-colored soils of the alpine region.--These soils are found above timberline at elevations between 3,300 and 3,600 m. Average annual temperature is less than 0°C; however, daily and seasonal surface temperature ranges in the microlayer are often extreme. Parent materials are generally basalt and granite, with lesser areas of shale and sandstone. Bedrock, often near the surface, is usually no deeper than 25-75 cm.

Soils in topographic depressions are often poorly drained, are high in organic material, and peaty. Well-drained areas are dark colored, high in organic material, and generally acidic. Textures range from gravel, stoney, to sandy loam. Subsoils are mostly gravelly or stoney sandy loams, readily permeable and mildly acidic. Productivity is low because of the low soil temperature.

The baseline soil chemistry is not available for the soil types in the Flat Tops Wilderness area. As a result, it is difficult to identify changes that could occur as a result of materials brought in via atmospheric pathways. Acid-producing materials and toxic substances in significant concentrations will probably be more readily identified in other components of the ecosystem (e.g., lakes and vegetation).

RECOMMENDATIONS

Short Term

Judging from the available data, the most sensitive indicators of effects of atmospheric emissions on the hydrologic system are precipitation quality and the quality of poorly buffered lakes, such as Surprise, Upper Island, and Shingle. Streams, well-buffered lakes, and soils would probably not show observable effects of atmospheric emissions until much later than the most sensitive indicators. In response to PSD applications, the available precipitation and lake data, in combination with proponent-supplied estimates of deposition rates of phosphorus (P),

nitrogen (N), sulfur (S), and total acidity, will allow estimation of the effects on the precipitation, especially the snowpack, and the lake systems. In the absence of estimated deposition rates, it should be assumed that some lakes with present low pH values could show some lowering of pH and related fisheries impairment.

Long Term

Although available data are sufficient to indicate that even minor additions of pollutants will produce undesirable effects on the most sensitive indicators, quantitative evaluation of cumulative effects and even of future PSD applications will require substantial new data and data interpretation capability. Primary needs are for greater sampling density, knowledge of the present variability, identification and quantification of critical watershed processes, and models capable of relating cumulative emissions to deposition rates. Therefore, a major monitoring program, as described below, is warranted.

1. Streams.--The USDA Forest Service plans to continue monitoring stream water quality in and adjacent to the wilderness boundary to fulfill the direction outlined in the Flat Tops Wilderness Management Plan and Forest Watershed Management goals. Based upon analysis of the Forest Service's water quality data and specific monitoring needs identified in this workshop, we recommend the monitoring plan be modified by reducing the existing 11 monitoring stations to 6 and adding 2 to 3 new sites in high elevation headwater areas.

A CLUSTER analysis of Forest Service water quality data from 1978 to 1980 indicates there is not a significant difference between the water quality measured at several of the 11 stream monitoring stations. This is attributed primarily to homogeneous geologic conditions in these watersheds. Based upon this analysis, it would be more efficient to reduce the existing 11 sites to 6. Although the data suggests these streams are alkaline and, as such, not good indicators of acid pollution, they are needed to provide valuable information on long-term cumulative impacts associated with offsite development. In addition, because the six monitoring sites are located in the lower portion of major drainages and at similar elevations, we recommend adding two to three stations in high-elevation headwater areas. These stream systems may not be as alkaline as the lower sites and, consequently, are expected to be more sensitive to impacts of atmospheric deposition. These new sites can be identified after a synoptic reconnaissance of the high-elevation streams.

2. Precipitation.--The existing data base is hampered by the small number of stations,

short length of record, and lack of data for the high-altitude areas where the most sensitive lakes are located. Data on precipitation quality are especially inadequate. Long-term wet/dry precipitation collectors with associated meteorological monitoring equipment, as well as a network of quantity/quality snow courses, should be established. It is especially important to measure quality of the snowpack on the mesa above 3,150 m.

Related to the precipitation data needs is a need for an applicable atmospheric transport/deposition model. This model should be capable of handling both regional and local emission sources and of calculating deposition rates at altitudes in excess of 3,150 m.

3. Lakes.--After reconnaissance-level investigation is complete, the lakes should be grouped into categories representing various levels of alkalinity and productivity. Representative lakes of these groups should be selected for long-term monitoring and for investigation of critical system processes. Monitoring should include both biological and chemical components of the system. Algal, invertebrate, and fish population structures, and primary productivity would be suitable for the biological component. Chemical components should include diurnal characteristics of pH and dissolved oxygen as well as major ion, major nutrient, and selected trace constituent analyses. Sampling frequency should be sufficient to identify the normal seasonal variation in many of these characteristics.

Critical system processes also include both biological and chemical components. Biological processes should include bioassay of primary producer and other trophic-level response to nutrients and toxic constituents expected from atmospheric emissions (e.g., boron (B), molybdenum (Mo), arsenic (As), phosphorus (P), nitrogen (N), and fluorine (F)). Reproductive success and relationships between predators and prey should also be evaluated.

Chemical processes should include evaluation of budgets for indicator chemical components, including determination of sites of weathering and probable response to pH changes in precipitation. Also important would be the mechanisms of constituent recycling within the lakes themselves, particularly for nutrient species.

4. Soils.--In addition to baseline soil chemistry--cation-exchange balance, nutrient levels, trace elements, and microbiology--a statistically reproducible sampling methodology needs to be developed. It may well be that certain microfauna in the soils at high elevation are sensitive indicators of changes in soil trace elements. These have not been identified, nor have threshold levels been determined.

3. FISH AND WILDLIFE

J. Newman, K. Schreiber, L. Jensen,
B. Rios, and J. Sarazin

INTRODUCTION

Present and future development of oil shale in the vicinity of the Flat Tops will affect existing and future air quality of the area and, possibly, the fish and wildlife resources of the wilderness area. Objectives of this report are to:

1. Identify air quality related values (AQRV's) for fish and wildlife in the Flat Tops and sensitive receptors that may exist for each value.
2. Determine what information regarding fish and wildlife AQRV's is either presently available or needs to be collected in order to review and make recommendations for oil shale PSD permits.
3. Determine what short-term and long-term monitoring of fish and wildlife may be necessary on the Flat Tops to measure possible effects on fish and wildlife AQRV's from oil shale development.

EXISTING RESOURCES

The major species of fish in the Flat Tops Wilderness include the native cutthroat, rainbow, and brook trout. Many of these are stocked by the Colorado Division of Wildlife because there is heavy fishing pressure on most fisheries in the wilderness area.

Large mammals found in the Flat Tops Wilderness include American elk, mule deer, black bear, coyote, and mountain lion. Elk and deer are very important to the area recreationally, economically, and biologically. The White River elk herd is one of the largest herds in Colorado, with 4,000-5,000 animals present in the area during the summer. This herd has, in the past, been known to be one of the best herds for trophy hunting, and it is located in one of the finest hunting areas in the state. Portions of the largest deer herd in Colorado summer on the Flat Tops. The abundance of black bear results in many conflicts with domestic sheep during the summer. Coyotes are also very abundant in the area and also cause conflicts with domestic sheep bands. There are no grizzly bears or wolves present. The Colorado Division of Wildlife is planning to reintroduce bighorn sheep into the Sheep Mountain vicinity on the eastern side of the wilderness area.

Small mammals commonly found in the area include snowshoe hares, ground squirrels, pine squirrels, chipmunks, pocket gophers, pikas, porcupines, and marmots. Dominant furbearers include the red fox, bobcat, coyote, weasel, and beaver.

A wide variety of bird life is present, with cavity nesters such as woodpeckers, sapsuckers, and flickers being abundant. Raptors such as red-tailed hawks, Swainson's hawks, golden eagles, and great horned owls are common. Blue grouse, ptarmigans, juncos, finches, crows, ravens, jays, and Clark's nutcrackers are also found in abundance. Waterfowl such as mallards and teals use the many small lakes in the wilderness.

DEFINITIONS AND ASSUMPTIONS

Several assumptions and definitions served as the basis for developing the fish and wildlife AQRV's. In identifying AQRV's and the possible significance of air pollution upon them, the legal concept of wilderness was kept in mind. The AQRV's suggested are values that, if changed, might have an adverse effect on the Flat Tops Wilderness. The AQRV's defined by this group reflect a hierarchal progression starting with (1) values of societal significance, progressing down through (2) ecological or wilderness management values, and ending with (3) values reflecting specific fish and wildlife species of special recognizable value otherwise not covered.

There is a lack of species-specific information on dose/response relationships for many of these fish and wildlife AQRV's. We have, therefore, attempted to identify those that potentially could be affected by air pollutants. This identification is based on our present understanding of the reported effects to specific fish and wildlife groups or analogous groups such as domestic animals. It is assumed that three pathways of contamination of fish and wildlife by air emissions will exist: inhalation, ingestion, and absorption. In terms of priority, the second level of AQRV's may be considered of highest priority to the Forest Service because these AQRV's relate most directly to the Flat Tops Wilderness management plan.

For the purpose of this group report, the term "adverse effects" is based on measuring a change from the natural state, including physiological, behavioral, and/or ecological change.

Categories of AQRV's

Suggested AQRV's related to fish and wildlife of the Flat Tops Wilderness area, along with suggested sensitive receptors, are grouped into three hierarchical levels or categories:

1. AQRV's of general societal significance: Values for fish and wildlife, based on human use, that may be affected by changes in air quality.
 - a. Big game hunting--elk, deer.
 - b. Sport fishing--cutthroat trout.
 - c. Wildlife esthetics (photography, bird watching)--elk, pika, ptarmigan, others.
 - d. Trapping--beaver, marten, weasel.
2. Wilderness management AQRV's: Ecological indicators used for monitoring wilderness value (highest priority).
 - a. Indicators of ecotypes.
 - (1) Streams, lakes.
 - (2) Spruce-fir.
 - (3) Aspen.
 - (4) Riparian.
 - (5) Alpine-meadows.
 - (6) Grassland.
 - b. Indicators of important functional wildlife groups based on established relationships between the groups and their habitat requirements.
 - c. Indicators of wilderness integrity.
 - (1) Wildlife species richness/diversity.
 - (2) Wildlife health/vigor (e.g., as detected through tissue/organ analysis).
 - (3) Habitat quality.
3. Special species AQRV's: Fish or wildlife species, other than those above, that merit special concern because of special legislation, scientific value, or sensitivity to air quality degradation.
 - a. Endangered/threatened species--federal and state (e.g., Colorado greenback cutthroat trout).
 - b. "Type" species--gene pool preservation, endemic species/subspecies, voucher specimens.
 - c. Species at the edge of their range or in restricted habitats (e.g., habitat requirements are barely met), such that any additional stress (e.g., air quality degradation) may produce detectable change in their population and/or their range.

- d. Other species especially sensitive to air pollution, (e.g., aquatic or terrestrial invertebrates).

Interception Points

Fish and wildlife encounter or are exposed to air pollutants directly from the air; indirectly through vegetation, soils, or other land-based routes; and indirectly through the water. The exposure medium on the point of interception should be identified for each specific fish and wildlife AQRV.

Air

The airshed is the first point of interception for fish and wildlife species of airborne pollutants. Receptors at this level might include bird species or flying insects which would inhale pollutants. Lung tissue in selected species would be the sensitive receptor.

Land

The next level of interception, the land, is more complicated because it reflects possible modification of the original pollutant by interaction with vegetation, soils, etc. Terrestrial species, which might be affected directly by inhalation, may also be affected indirectly through ingestion of contaminated vegetation or water. Primary consumers could be the first-level receptors.

Water

Water systems represent a third, and perhaps most complicated, level of interception because the air pollutant may have interacted with vegetation and soil before settling in the aquatic systems; thus, its effect may be greater than or less than in its original form (i.e., biomagnified or converted into more toxic forms).

Selection of Sensitive Receptors

Criteria for selecting sensitive receptors (indicator species) should include the following:

- A. Ease of monitoring as determined by
 1. abundance
 2. census techniques
 3. costs.
- B. Certainty of diagnostic effects of receptors to air emissions emphasizing
 1. species with known physiology, life history, etc.
 2. species with known sensitivities or sensitive life stages.
- C. Ecologically important species including
 1. stenotrophic sensitive species

Table 3.--A preliminary attempt at identification of
sensitive receptors for fish and wildlife AQRV's

Categories of AQRV's	Interception points		
	Air	Land	Water
<u>Societal significance</u>			
Big game hunting	None	Elk - aspen quality Deer-browse quality	None
Sportfishing			Cutthroat trout - alkalinity changes
Wildlife esthetics	White-crowned sparrows - lulls	Elk - aspen quality Ptarmigen - willows Pika - food	None
Trapping	None	Beaver - aspen quality and quantity	Beaver - water quality - aquatic vegetation

2. species with critical/sensitive life stages
3. species with unique habitat characteristics
4. species at extension of their range or living naturally in suboptimal habitats.

elements such as nesting success and clutch size of raptors and insect-avaricious birds. The land interception point might consider elements such as sex rations, calf crop, and teeth of harvested elk and deer. The water interception point might consider productivity and growth of salmonid fishes and the like.

RECOMMENDATIONS AND NEEDS

A Matrix Approach

Specific Information Needs for the Flat Tops Wilderness

It is suggested that a matrix format be developed in which the rows represent categories of AQRV's broken down to specific levels within the three general categories (1) societal significance, (2) wilderness management, and (3) special species, considerations mentioned earlier. Three columns representing the interception points--air, land, and water--would be used to fill out the matrix. Data to be placed in the matrix would be specific species of fish and wildlife as critical biological, chemical, or physical elements which can serve as an indicator or most sensitive species for that AQRV category at that interception point.

For example, under societal significance, the breakdown shown in table 3 might occur.

It is somewhat more complicated to complete the remainder of this type of matrix. The three subcategories under wilderness management break down into a large number of individual ecotypes, of habitat/functional groupings, and of wilderness integrity measures. Indicator species/elements must be determined for each interception point. For example, a wilderness integrity measure selected might be wildlife health and vigor. The air interception point might consider

Relatively good information exists on the Blanco and Rifle Districts regarding the fish and wildlife resources of the Flat Tops and their ecological interactions. This information needs to be compiled and synthesized for refining and/or identifying sensitive receptors for some of the AQRV's. Inventories exist on most vertebrate species, with the possible exception of reptiles, amphibians, nonsalmonid fish, and on key terrestrial and aquatic invertebrates. General habitat and food relationship information exists for most fish and wildlife groups. This information needs to be synthesized and significant data gaps identified. A preliminary list of information needs for the Flat Tops would include:

1. Identification of wilderness management AQRV's as related to wildlife groups:
 - a. Indicator species of each group.
 - b. Groups classified by habitat considerations.
2. Identification of endangered and threatened species and of their actual or potential locations.

3. Identification of species' extension of their ranges as restricted by habitat.
4. Identification of fish and wildlife species sensitive to air pollutants.
5. Identification of ecological attributes of wilderness area as they relate to:
 - a. Identification of wildlife species, numbers, and kind--vertebrate, invertebrate, insects, etc.
 - b. Vigor and health of wildlife.
 - c. Quality of fish and wildlife habitat.
6. Exposure routes for air contaminants including inhalation, ingestion, absorption.
7. Effects of contaminants, including both short- and long-term effects; information on seasonal exposure potential (i.e., snow melt pH changes in aquatic systems) is needed.
8. Seasonal sensitivity of specific AQRV's. Depending upon their age or life cycle, both fish and wildlife have differential sensitivity to toxic conditions. Information on these sensitive periods for each animal group needs to be developed.
9. Baseline levels of trace elements in AQRV's receptors in wilderness area.
10. Comprehensive inventories and mapping of wilderness area by ecological resources and by AQRV's.
11. Regional plan addressing location of facilities to avoid identified sensitive wildlife areas.
12. Coordination with U.S. Fish and Wildlife Service, USDA Forest Service, U.S. National Park Service, U.S. Bureau of Land Management, U.S. Geological Survey, and Colorado Division of Wildlife on common methods for air quality assessments.
13. Need for vegetation information on plant species that accumulate pollutants; and on vegetative species sensitive to pollutants, especially vegetation critical to wildlife habitat.
14. Need for air emission information for specific oil shale developments:
 - a. Air isopleths of pollutant concentration, along with descriptive statistical analysis of confidence limits. Used to identify hot spots.
 - b. Range of emission levels (high and low values) and frequency of occurrence of these values.
 - c. Air quality information at 1-hour averages in addition to 3-hour and 24-hour averages.

- d. Probability of inversions--where they could occur and how long they could last.
- e. Chemical composition of the particulates.
- f. Seasonal information on particulate deposition patterns.
- g. Direction of plume travel and rainfall information.

General Information Needs for Fish and Wildlife AQRV's

The weakest but most critical element for fish and wildlife AQRV evaluation is information on the effects of air emissions. Literature reviews have shown that fish and wildlife are known to be affected. However, the lack of sufficient usable information is not a function of tolerance of fish and wildlife to air emissions, but reflects the lack of observation and monitoring. It is recommended that generalized dose/response relationships for fish and wildlife AQRV-sensitive receptors be developed from existing information. These dose/response relationships could then be applied to establish screening levels for possible effects on representative animal receptor groups. Several scientist-months would be required for this task. Once the fish and wildlife AQRV's have been refined, specific dose/response relationships can be developed. Existing data bases should be reviewed, and an assessment of the potential hazard developed. Some dose/response information is available in the literature, but new testing may be required to supplement information gaps. Emphasis should also be placed on possible seasonal or life stage sensitivities of fish and wildlife to air emissions.

Coordination between the vegetation AQRV's and the fish and wildlife AQRV's is critical, especially in identifying indirect effects for fish and wildlife (i.e., habitat or food impacts). Along with the development of dose/response estimates for fish and wildlife, some standards need to be set for USDA Forest Service evaluation criteria that will be used in assessing whether a potential effect is likely to occur.

Monitoring Needs

For the short term, we recommend utilizing existing monitoring programs within the Flat Tops (i.e., Hunter Check Station, Trappers Lake Facility) to collect baseline information on the health and vigor of fish and wildlife. Information on standard measures of health and vigor should be collected and put in a form usable in a fish and wildlife AQRV assessment. In addition, selected tissues reflecting accumulation sites in mammals should be collected for later analysis to determine background levels of trace elements in selected sensitive receptors. Baseline monitoring should start soon and several years of preoperating data should be developed. Tissue analysis can be deferred until complete monitoring priorities

are established and AQRV's are refined. Once the fish and wildlife AQRV's have been refined, the AQRV resource map developed, and effects information collected and analyzed, a long-term monitoring program should be established to provide information for the key sensitive receptors and the changes during the development of oil shale.

PSD Permitting Procedures

Discussions by the participants led to a 6-step procedure that could be used by federal land managers in evaluating a PSD permit from a fish and wildlife AQRV's perspective.

Step 1a. Identify and develop fish and wildlife AQRV's and AQRV resource map for the area. Would be dependent on the number and location of AQRV's. The resource map could be an overlay format.

Step 1b. Develop specific sensitive-receptor-response information for AQRV's, such as the matrix discussed in the previous section.

Step 2. Obtain and review the PSD application. Ensure that emission type and concentration and deposition information, including isopleth maps for each air pollutant on the appropriate averaging times are available.

Step 3. Based on predicted concentrations identified in Step 2, screen fish and wildlife AQRV's to identify potentially affected values.

Step 4a. Compare location of potentially affected fish and wildlife AQRV's with PSD information on deposition pattern and concentration for each emission type.

Step 4b. Calculate/estimate exposure potential to AQRV's from land- and water-exposure routes.

Step 5. Identify potentially affected AQRV's, resource areas, and potential impacts.

Step 6. Make recommendations for PSD review or seek further information and repeat Steps 3 through 6.

4. VEGETATION

W. Lauenroth, L. Sohlt, J. Bennett, D. Summers,
and B. Peterson

INTRODUCTION

Deposition of air pollutants in the Flat Tops Wilderness can be expected both on higher elevation plateaus and lower elevation valleys. At the present time, two major pollutants from oil shale technology are considered phytotoxic: ozone (O_3) and sulfur dioxide (SO_2). More information on source emissions and modeling is needed to determine if acidity and metals and other chemicals present a threat.

EXISTING VEGETATION

The vegetation on the Flat Tops Wilderness consists of five major vegetation types: conifers, mixed grasslands, riparian shrubs, aspen groves, and marshes (table 4). Three of these types are patchy in distribution, while conifers and riparian shrubs form discrete stands or linear units. This composite of vegetation forms a continuous, integral system of interacting types which is essential for the multiplicity of uses the wilderness receives (table 4). Thus, while each type has value in itself for one or more uses, a higher value is found in the integral functions of all types (i.e., the whole is greater than the sum of its parts). In this sense, by recognizing that air pollution can affect any vegetation, each vegetation type is considered

an air quality related value (AQRV) and may not be isolated or ranked separately from or above any other.

Within plant communities, however, sensitivity of plants to air pollutants at different times of the year depend on the life cycle of the plants, the growth rate, and the life form. Perennial evergreens (conifers) and lichens may be susceptible all year, even though they may be most sensitive during active growth in the spring. The cone-producing season of pines (spring) may also be a sensitive stage of growth, affecting the ability of the species to regenerate. Lichens are especially sensitive to low levels of sulfur dioxide (SO_2), which occur throughout the year. Foliose lichens are more sensitive than crustose types. Deciduous perennial shrubs and trees (e.g., aspen) are most sensitive during the spring flush of new growth, and not sensitive at all after the leaves have fallen off. Both evergreen and deciduous trees are most sensitive to air pollution stress when very young or very mature. Air pollution stress at this stage may delay or speed up flowering, inhibit complete flower formation, decrease the number of leaves and flowers, and hasten mortality. Rosette plants are less sensitive than erectile plants, and grasses are noted for their high sensitivity to SO_2 .

Table 4.--Vegetation types of the Flat Tops

Types	Cover	Biomass	Patchiness	Uses
----(percent)----				
Conifers	60	80	No	Hunting, hiking watershed, animal shelter
Mixed grasslands	27	5	Yes	Grazing, camping, hiking, hunting
Riparian shrubs	1	4	No	Forage, fishing
Aspen	10	10	Yes	Esthetics, forage
Marshes	2	1	Yes	Waterfowl, hunting, fishing
	100	100		

Conifer

Older and overmature stands in the Flat Tops were killed by the spruce beetle epidemic of the 1940's. This opened the canopy and resulted in a lush and diverse understory community of forbs and grasses. The ground cover in the young spruce-fir stands comprises grass and forb species common to the area. Fir and spruce reestablishing on these sites have not had a great deal of influence on the understory community. This will likely change as succession continues and timber stands reestablish and close the canopy again. Fir is the dominant tree species reestablishing in the stands. The overstory is now 25- to 30-year-old trees, ranging in size from 3 to 10 m tall. This type is used mainly for wildlife food and cover.

Grassland

These areas are basically a stable community of grasses and of forbs with patchy stands of willow. Species of Deschampaia, Carex, Poa, Phleum, Trifolium, Mertensia, Potentilla, Agoseris, and Aquilegia predominate, along with Salix planifolia and S. brachycarpa. There are also a variety of lichens and mosses represented within this plant community.

The plant density and composition differs greatly with various slopes, moisture conditions, and soil productivity. Many of the grassland sites over 3,450 m approach an alpine tundra environment where the exposed ridges are typically sod-bound, tufted hairgrass stands, while the small draws contain stands of willow. This type is used primarily for grazing by domestic sheep, summer range for elk, sightseeing, backpacking, camping, and hunting.

Riparian

The riparian shrub types are located in the valley bottoms along the perennial streams. The sites are characterized by willows and plant species associated with wetter sites. Poa spp. and Carex spp. are the dominant grass and grass-like species. Numerous forbs are found. These areas are used primarily for wildlife food and water, fishing, hiking, camping, and domestic sheep grazing.

Aspen

Aspen sites are limited to sites below 2,850 m, generally on south-facing slopes. The understory is typically made up of grass species rather than the aspenweed type. The aspen are generally patchy, open stands. They provide thermal and protective cover and feed for elk and deer. Domestic sheep also show a limited amount of use of the aspen understory. The primary importance of the aspen may be visual because of the variety and color that they produce.

Marshes

Typical marsh sites are limited to portions of the eastern one-half of the upper plateau.

These marshlands have evolved over the years from barren potholes that had little vegetation around or in them, to a stage where a variety of carices, Juncus spp., and forbs thrive, at least along the shores. These sites are extremely wet in early summer; but, because of the porous, basaltic soil, parent material, these marshes lose most of the water by late summer. These areas are used for a minor amount of grazing by domestic sheep, elk, and deer.

BIOLOGICAL MONITORING OF VEGETATIVE AQRV's

An indicator species matrix is needed to evaluate adverse impact of the two major air pollutants from oil shale development on vegetation AQRV's (table 5). Several cells in this matrix have been filled, but a field visit by botanists would be needed to complete the matrix. The botanists must have expertise in nonvascular plants, particularly bryophytes, and general familiarity with Rocky Mountain flora. The matrix also identifies preferred responses to be measured on the indicator species. Finally, three miscellaneous indicators of high value that constitute additional AQRV's should be included: (1) rare and endangered species--none known, but knowledge is incomplete, (2) type localities--none known, but knowledge is incomplete, and (3) sphagnum bogs (peat)--acidic wetlands baseline. The botanical survey would also require checking for the presence of rare and endangered species, and any type localities of biotypes. Consultation with a local or regional taxonomic botanist at a herbarium would be the best way to check this. Finally, the presence of sphagnum bogs should be recorded to establish the baseline for acidic wetlands. Sphagnum moss grow best in acidic water.

Concentrations of sulfur and arsenic should be measured in plant samples to establish baseline conditions before oil shale development progresses.

LONG-TERM MONITORING

A two-stage program for the vegetation related AQRV's will provide adequate monitoring of air pollution impacts. The first stage utilizes the most sensitive plant species to alert the land manager that air pollutants are reaching the wilderness in potentially significant quantities. While the biological significance of impacts to these sensitive species may not be understood, their importance to the monitoring program is that they trigger the second stage. The land manager will have to make a decision regarding the action to be taken should the sensitive monitors begin showing responses to air pollution.

The second stage of the monitoring program involves collecting data from important species in each of the five major vegetation types. These species will be selected based upon their ecological importance or their value in influencing the uses of each of the vegetation types. As examples, Englemann spruce will be monitored because

Table 5.--Vegetation AQRV's indicator species matrix:
summary of what to look for, what is not known,
and indicator responses to air pollutants^a

Vegetation type	Ozone		Sulfur dioxide	
	Upland	Lowland	Upland	Lowland
Conifers	Engelmann spruce 1,2,4	Lodgepole pine 1,2,4	(Lichens) 1,5,3	?
Mixed grassland	?	Agropyron sp. Koeleria sp. Poa sp. Response 1,3,5		--
Riparian shrubs	?	?	?	
Aspen	1,4	1,4	1,4	1,4
Marshes	?	Duckweed (?) 6	?	?

^aIndicator responses to air pollutants:

1. Visible injury symptoms on leaves (e.g., O₃ flecking).
2. Reduced pine needle retention (e.g., "tufted" branches on ponderosa pine).
3. Sulfur concentration in leaves (once baseline is established).
4. Reduced tree ring increments.
5. Reduced species population abundance and distribution.

of its importance as one of the dominants in the spruce-fir vegetation type, while parry clover will be monitored in grassland type because of its importance as a forage species and its importance as a potential nitrogen fixer.

An important basis for adopting this approach is the low probability of impacts if the Class I PSD increments are not exceeded. One major concern, however, is with inadequate information about potentially high concentrations of ozone (O₃) over the wilderness area. There is currently nothing in the scientific literature that would support the idea of biological effects if the Class I increments for SO₂ are not exceeded.

In addition to use of two stages of biological monitors, it is suggested that in the first stage, two locations be emphasized: the highest

elevation sites and sites located in drainages. The valley sites will be closest to areas becoming urbanized in concert with the shale industry. The high-elevation sites should be more vulnerable to air pollutants released through tall stacks from power plants to the north and the oil shale industry to the west.

First-stage Monitors

Exposures of vegetation to air pollutants should be monitored by utilizing the most sensitive plants in the wilderness area (table 6). Lichens and bryophytes are the two plant groups most sensitive to SO₂ exposures. Lichens have been reported to respond to SO₂ concentrations considerably below those to which vascular plants respond (Linzon 1978). Bryophytes also provide a very sensitive monitoring capability for SO₂ (Smith 1981), although they have not been used as

Table 6.--Proposed first-stage biological monitors for impacts of air pollutants on the vegetation of the Flat Tops Wilderness area

Pollutant	Landscape positions	
	High elevation	Valleys
Sulfur dioxide	Lichens in spruce and fir trees	Lichens in ponderosa or lodgepole pine and aspen
	Lichens on soil surface and rocks in grassland	Bryophytes
	Bryophytes	
Ozone	Needle retention in spruce and fir	Needle retention in ponderosa or lodgepole pine

widely as lichens. Since the sensitivity of lichens and bryophytes to ozone is not as well established, monitoring of needle retention in the conifers has been proposed. Needle retention in many conifers has been reported to be quite sensitive to exposure to oxidant air pollution (Miller and McBride 1975).

Based upon the results of a botanical survey of the Flat Tops, species of lichens should be selected from the spruce-fir forested areas and the grasslands as SO₂ exposure monitors. In the forest, these should be on the epiphytic lichens. In the grasslands, a species growing on the soil surface should be used; in the highest areas, lichens growing on rocks; and in the drainages, epiphytic lichens associated with aspen and pines.

At the high-elevation locations, needle retention in Englemann spruce should be used to monitor exposures to ozone. In valleys, similar assessments of ponderosa pine and/or lodgepole pine should be made.

Second-stage Monitors

The species utilized in this part of the program should be selected by criteria other than their known response to air pollutants (table 7). The concern here is with potential impacts of direct significance to the integrity and uses of the wilderness area. For SO₂, the sulfur content in the leaf tissues of important species in each vegetation type was selected despite our awareness that the effects of a change in the sulfur content of a plant as a result of exposure to SO₂ are not always easily interpreted. Sulfur content is often one of the first items altered as a result of SO₂ exposure.

Ozone exposure may be more difficult to document on a variety of species. Because exposure of a plant to O₃ often leaves no symptoms except tissue death, we have proposed utilizing

visible leaf injury to important species as the indicator of O₃ exposure.

A response indicating air pollution exposure by one or more of the second-stage monitors should trigger additional investigations that could be of more direct ecological significance. They would include such things as increment borings to determine growth rates, biomass and density estimates of trees, species composition and productivity of grasslands and marshes, and growth rates and density of riparian shrubs.

PREDICTION OF AIR POLLUTION IMPACTS

As time series data are available for pollutant concentrations, ecological simulation models may provide a capability for predicting ecological impacts based upon the newest and most sophisticated effects data available. Simulations can be accomplished much less expensively than field sampling, and new information can be incorporated into the model rapidly. The limitations to using ecological simulator models are similar to those of meteorological dispersion models.

Sampling Design

Selection of sampling areas within the wilderness area should be a reflection of expected air quality gradients. A grid system of sampling stations should provide a selection of sites that reflect the variability of air quality in the wilderness. Ten to 30 sampling stations will provide a reasonable array of sampling stations. The logistic and economic factors will be major determinants of the number of sampling stations selected. Sampling stations should be selected so that edaphic, topographic, and micrometeorological variation among them is minimized. At each sampling station, a minimum of 10 subsamples should be selected for each characteristic to be monitored (e.g., arboreal lichen densities or

Table 7.--Proposed second stage biological monitors for impacts of air pollution on the vegetation of the Flat Tops Wilderness

Vegetation type	Pollutant	
	Sulfur dioxide	Ozone
Coniferous forest	Sulfur content of spruce and fir needles	Needle retention in spruce
Grassland	Sulfur content in foliage of tufted hairgrass and willow	Visible leaf injury to parry clover
Riparian	Sulfur content in willow leaves	Visible leaf injury to aspen
Aspen	Sulfur content in foliage of aspen and Canada wild rye	Visible leaf injury to aspen
Marsh	Sulfur content in tall larkspur	Visible injury to tall larkspur

sulfur content of aspen leaves). It is probably more important to pare down the number of sample areas selected in order to maintain a sufficient number of subsamples to provide reasonable estimates of statistical parameters. An annual sampling scheme should be sufficient to identify responses to changes in air quality.

Data Collection

Exposure monitoring.--Lichens are expected to be the most sensitive indicators of SO₂ dosages on the wilderness area. In the forested habitats, arboreal lichens are expected to be the primary monitoring indicators. At each station, at least 10 trees can be selected, and density of lichens per tree can be determined for each sampling period. Crustose lichen densities can be estimated from 10 or more selected quadrants on rock or soil substrates. Differential changes in densities of lichens among sample stations will reflect differential environmental factors affecting the station site.

Ozone effects may be best reflected in conifer needle retention. At each sample station, a number of branches from at least 10 selected individual trees can be examined to estimate the average number of needle bundles per branch. Differences in the rate of needle retention from year to year among sample stations will reflect differential environmental factors affecting station sites.

Effects monitoring.--In order to monitor effects to local vegetation communities, plant tissue sulfur content has been selected as an indicator of SO₂ effects, and visible leaf injury as an indicator of O₃ effects. Leaf tissue

samples of each indicator species can be collected at each sampling station and returned to the laboratory for chemical analysis. Increasing tissue sulfur contents with time and exposure intensity will indicate incipient SO₂ effects upon the local biota. Increasing frequency of observable leaf damage with time would be indicative of incipient ozone damage to the local vegetation communities.

Data Analysis

Leaf tissue can be dried and sent to an analytical laboratory for standard chemical determination of sulfur content.

Records of observation of needle retention, lichen densities, and leaf damage frequencies should be recorded in such a manner as to be readily extracted for statistical analyses. The numbers can be analyzed by standard statistical methods (including analysis of variance) to detect any differences among sampling stations.

Interpretation

Differences among sampling stations may be interpreted as being due to changes in air quality if one can demonstrate that air quality variation is the dominant independent variable among the stations. The confidence that one will have in such an interpretation is an inverse function of the variance of other independent environmental variables that characterize the stations.

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5. AIR QUALITY SIMULATION MODELING

R. Drake, D. Fox, and J. Carson

INTRODUCTION

Objectives

The objectives provided to the modeling group were:

1. Review modeling currently available.
 - a. Develop a listing of all ongoing modeling relevant to western Colorado (SAI/EPA, LASL/NCAQ, DOE/Argonne-Battelle) (see appendix B).
 - b. List concentration projections for the Flat Tops Wilderness area for different levels of industrial development.
 - c. Critique the various modeling exercises.
2. Review the adequacy of current modeling from the perspective of evaluating air quality related values (AQRV's) on the Flat Tops Wilderness.
3. Develop plans to identify what should be done to bridge any gaps between the modeling that is available and modeling needed.

Need for Modeling

An air quality simulation model is a quantitative method, based on physical principles, used to estimate pollutant concentrations in a specific area and period of time. Concentrations are dependent on at least two major factors: (1) the location, nature, and magnitude of emissions and (2) the meteorological conditions to which the emissions are subjected as they are transported, possibly transformed chemically, and diffused. The Clean Air Act and subsequent regulations require the use of air quality simulation models to estimate the concentration resulting from new sources. In particular, the contribution of a new source to existing concentrations of criteria pollutants cannot cause any exceedance of the National Ambient Air Quality Standards (NAAQS), or of any state ambient standard. The criteria pollutants are SO_2 , PM, CO, O_3 , NO_x , NMHC, and Pb.

Locations where the NAAQS's are currently being met are designated Prevention of Significant Deterioration (PSD) areas and classified as either Class I (the most protected areas, which include most national parks and wilderness areas that existed prior to August 7, 1977, as well as any other areas designated by the state);

Class II (virtually all the remaining land); or Class III (a designation allowing greater development than Class II). The Flat Tops is a mandatory Class I area (established by the 1977 Amendments to the Clean Air Act), while all the surrounding areas currently are Class II. In Class II areas, there are annual, 24-hour, and 3-hour average increments of SO_2 and PM concentrations that accumulate with each new permitted source until a particular level is attained. If, in a Class II area, the increment is calculated (by a model) to cause the level to be exceeded, the facility cannot be permitted; it then becomes necessary to consider either a greater level of emission control, relocation, offsets, or, perhaps, an improved model and a field study to validate it. While there are also Class I increments, they serve more as a guide to the determination of any adverse impact on AQRV's (including visibility) of the Class I area, than to an absolute "yes/no" decision. Although the increments apply only to PM and SO_2 , AQRV's are to be protected against all pollutants. This protection is afforded through the affirmative responsibility of the federal land manager (40 CFR 52.21(q)).

There are three basic outputs for adequate air quality modeling: (1) point values of ground level maximum concentrations of pollutants that have NAAQS or state AAQS, and of SO_2 and PM increments for PSD (regulatory modeling); (2) concentration distributions aloft of appropriate chemical constituents (e.g., PM, SO_2 , sulfates, nitrates), to determine visibility impairment within the Class I area and along any integral vistas promulgated by the state (40 CFR 51.304); and (3) distribution of chemical materials (e.g., SO_2 , PM, sulfate nitrate, NO_x , O_3 , heavy metals), deposited, especially to the Class I areas, which could be expected to cause an adverse impact to AQRV's. These requirements call for concentration estimates on time scales ranging from 1 hour up to 1 year. The modeling required is illustrated in figure 3 (see p. 5).

MODELING ACTIVITIES

This listing of modeling activities is broken down between operational and research activities. While EPA air quality regulations require operational modeling estimates, it is generally recognized that these estimates are in need of refinement (Fox and Fairbent 1981). At the present time, EPA has no "recommended" model for application in complex topographic locations such as western Colorado. This results in the use of recommended "screening" technique (the so-called "valley" model) by default. Screening technique

are characterized as conservative, first-cut approximations. The use of such techniques may very well lead to premature and incorrect increment consumption. Recently, a set of statistical procedures has been developed to quantify comparisons of predictors from an air quality simulation model and observations (Fox 1981). The EPA is adopting these procedures for use in evaluating a new model and allowing its use for regulatory decisions.⁶ This procedure calls for an extensive, site-specific field study to develop the data necessary to conduct this evaluation. Thus, modeling that is now categorized as research may very well become operational for PSD permitting in the next few years. Model development research is being conducted primarily by EPA- and DOE-supported National laboratories, while the federal land managers, universities, and some consulting companies are also involved. Application of models is done by all these groups and more. Discussions regarding the accuracy of modeling are included in the above references.

Operational Modeling

1. Colony Oil Shale Project--Near-Source Model

A comparison of valley and plateau location of a plant in Parachute Creek drainage through the use of a Gaussian plume model, with dispersion coefficients modified by field tracer data.

2. Various Developers--Preliminary Modeling Results

Results determined long- and short-term ground level concentrations from various unit operation scenarios using the EPA valley model and box models of one sort or another to account for limited mixing effects, rough terrain, and stagnation episodes.

Some developers have used other varieties of Gaussian plume models for near-source and mesoscale transport. Most of these activities are referenced in an Office of Technology Assessment (1980) report.

3. EPA/Denver Research Institute--Assessment Models

Results from a study by Systems Applications, Inc., using (a) modified Gaussian valley model to calculate SO₂ and PM maximum concentrations near the sources, and (b) a reactive plume model to determine long-term regional impacts on ambient NO_x, O₃, SO₂, PM, and visibility.

4. NCAQ/Los Alamos National Laboratory--Impact Modeling

A modified Gaussian approach using suggestions recommended by the National Commission on Air Quality (Fox and Fairbrother 1981) to estimate increment consumption by shale developments. In addition, visibility calculations for surrounding Class I areas are presented.

Research Modeling

5. EPA/University of Minnesota--Simple Aerosol Model

This is not oil shale oriented, but may be used as a simple module for particle/particle interactions.

6. EPA/RTP--Regional Oxidant Model

A regional scale model is under development primarily for application to the north-eastern United States oxidant (O₃) problem by EPA in Research Triangle Park, N.C. (RTP). This model probably will not be easily adapted to oil shale applications.

7. EPA/ERT--Complex Terrain Model

A point-source, complex terrain, model development and evaluation effort is being conducted for EPA by Environmental Research and Technology, Inc. This effort will result with a replacement for the EPA valley model within the next five years. It should see major applications in the shale region.

8. EPA Region VIII/Systems Applications, Inc.--Regional Model

Model developed for high plains coal assessment--may be modified for oil shale, but only with significantly higher funding than now available.

9. EPA Headquarters/BATTELLE Northwest Laboratories--Mesoscale/Local

A grouping of models on various scales for application to the oil shale region, including the following:

- a. Regional flow model--This model provides wind profiles needed to run a mesoscale, mass-consistent, wind field model.
- b. Mesoscale flow model--A mass-consistent wind field model that is terrain-following and accommodate variable densities.
- c. Mesoscale air quality model--This model is under development based on the Lagrangian Puff approach accounting for wet/dry removal and coupling/decoupling with local flows. It will be designed to accept reaction, aerosol, and visibility modules developed by others.

⁶Interim proceedings for evaluating air quality models. 64 p. An unpublished report by Environmental Protection Agency, OAQPS, SRAB, Research Triangle Park, N.C., 1981.

- d. Local scale flow and air quality models
--An analytical model to simulate radiation-driven growth of the convective boundary layer (CBL) in mountainous terrain coupled to a sector-averaged, analytical, air quality model has been developed. It will be used to estimate the time period of coupled/decoupled flows that will provide coupling coefficients for the mesoscale air quality model.

10. USDA Forest Service/CSU--Planning Models

The topographic air pollution analysis system (TAPAS), including the following:

- A diagnostic, two-dimensional wind field model (WINDS) (Fosberg et al. 1976).
- A Lagrangian puff dispersion model including plume rise, dispersion, and terrain corrections.
- A local box model with variable mixing depth for application to community area sources (Howard and Fox 1979).
- An estimate of pollution potential through a simple dispersion model which is useful for planning purposes (Fox and Fosberg 1977).

11. EPA Headquarters/Systems Applications, Inc.
--General Policy Alternatives

Gaussian and ventilated box models are used to study management alternatives available for western Colorado.

12. USDI BLM/Systems Application, Inc.--Regional Modeling Assessment

Conduct of a regional modeling exercise to aid in oil shale leasing for Utah and Colorado State areas.

SELECTED MODELING RESULTS FOR FLAT TOPS

1. EPA--Valley-type Calculations

- Office of Technology Assessment (1980) projections

- (1) 65,000-bpd industry, wind blowing toward Flat Tops, gave 20% of Class II 24-h PSD increment for PM and 33% PSD increment for SO₂, which when scaled up leads to a 217,000-bpd limit on SO₂ and a 325,000-bpd limit on PM.

- EPA--Region VIII assessment⁷

- (1) 1976 prototype lease evaluations for 200,000-bpd total production were estimated to yield the following 24-h average values:

Area	TSP	SO ₂
	---(µg/m ³)---	
Dinosaur National Monument	18	5
Colorado National Monument	<3	<1
White River National Forest	8	<2
Ashley National Forest	5	1

- (2) PSD permits issued on the basis of this modeling through 1979 will accommodate 62,000-bpd production with an associated Flat Tops impact of 1.5 µg/m³ for 24-h average SO₂ and 2.0 µg/m³ for 24-h average PM. Scaling this up to the Class I increment suggests a limitation of 207,000 bpd by the SO₂ increment and 310,000 bpd by the PM increment.

2. EPA--Box model type calculations⁷

Assumptions made in this calculation included (a) a single box, 40 km wide, with a variable height of inversion; (b) "Colony type" emissions; (c) no chemical transformation of any emissions; (d) no deposition; (e) no dispersion out of box; and (f) homogeneous mixing of pollutants throughout the box instantaneously.

For the maximum 24-h average impact at the Flat Tops Wilderness, results were estimated using the assumed mixing heights and wind speeds shown at the following values:

Mixing height	Wind speed	TSP	SO ₂
(m)	(mps)	---(µg/m ³)---	
2,500	6	0.4	0.5
1,000	5	1.3	1.6
500	5	2.6	3.2
500	3	4.4	5.4
400	4	4.1	5.0

3. EPA estimates based on PSD permitted emission rates⁷

Permitted emission rates as a function of oil production levels (pounds

⁷Paper given by T. L. Thoem at Brown Palace Hotel, Denver, Colo., June 19-20, 1980. Entitled EPA and oil shale.

per barrel of oil) from four PSD permits that have been issued are summarized as follows:

Pollutant	Colony	Union	Cathedral Bluffs	Rio Blanco
SO ₂	0.164	0.237	0.160	0.668
NO	0.903	0.291	--	--
HC ^x	0.158	0.125	--	--
PM	0.134	0.102	--	--
CO	0.036	0.172	--	--

4. EPA--comparison of impacts of oil shale (Colony permitted emissions) versus power plants (tons per year)

Pollutant	50,000 bpd	1,000 MW power plant
SO ₂	1,239	13,790
PM	1,008	1,062
NO _x	6,817	17,714

5. Systems Applications, Inc., and NCAQ/LASL

Both the SAI (Anderson et al. 1980) and the NCAQ/LASL (Williams and Mangeng 1980) modeling exercises use a modified Gaussian valley type dispersion model. Results are listed in table 8.

VARIATIONS IN MODEL ESTIMATES

Differences in the numbers presented in table 8 are caused by four factors:

1. Different emission factors and magnitudes--some studies account for fugitive emissions and some do not. There is great uncertainty

in the emissions from the oil shale projects because they are only prototypes with emission control equipment not yet determined.

2. Use of different, and sometimes contradictory, spatially uniform winds. There is insufficient information to know if measured winds are representative of the entire area. The meteorology of the region must be better characterized.

3. Different assumptions regarding plume rise and its interactions between mixing heights and atmospheric stability are made within models. Data specifying stability and mixing height are not uniformly treated and may not be representative--again the meteorology must be better characterized.

4. Different assumptions on diffusion coefficients removal processes and other model parameters are made in models--agreement on acceptable models and modeling technology is being sought but should be more strongly encouraged.

ADEQUACY OF MODELING FOR AQRV ANALYSIS

The modeling that has been done so far is totally inadequate to evaluate impacts on air quality related values (AQRV's) of the Flat Tops Wilderness. Reference is made here to figure 3 (p. 5), which illustrates that a rather complex array of modeling must be developed in order to assess impacts on the Flat Tops Wilderness in a rational manner.

The modeling displayed in this section is regulatory modeling. It is done to identify acceptable levels of development. The examples shown are often large, generalized assessments and not necessarily as accurate as is possible. The emissions data and the meteorology used by the models are gross approximations of what actually might occur. The models themselves are either

Table 8.--Flat Tops concentrations resulting from modeling exercises

Pollutant	Appropriate standard	1995 SAI 880,900 bpd	1995 NCAQ/LASL 939,000 bpd
SO ₂		----- (µg/m ³) -----	
3-h	25	12	21
24-h	5	--	5.1
Annual	2	--	0.3
PM		----- (µg/m ³) -----	
24-h	10	7	3.6
Annual	5	--	0.2
O _x		----- (ppm) -----	
1-h	0.12	0.106	
NO _x		----- (ppm) -----	
Annual	0.05	0.002	

designed or degraded to produce only a single worst-case number for concentration at a point. This modeling is most appropriately interpreted as an index required by law and regulation in order to determine how much development will be allowed. This approach could have been used to protect Class I areas; in fact, the Class I increment concept is a representation of it. However, Congress enforced this approach by providing federal land managers with a more substantive responsibility; namely, an identification of impacts on Class I areas and a determination of the potential adversity of those impacts. In order to accomplish this, the federal land manager must consider the pollution field that is deposited over an extended time period; namely, the dosage that results to various receptors in the Class I area. Considerably more sophisticated modeling is needed to accomplish this, and a substantial effort will be needed to evaluate the effects of these projections of AQRV's.

NEEDS FOR ATMOSPHERIC DISPERSION MODELING TO ASSESS AQRV IMPACTS

Basically there are needs to (a) improve the air quality models for application to multiple sources in complex topography (this will require enhanced fundamental knowledge in mountain meteorology), (b) provide the data (emissions and meteorology) required for operational application of the models, and (c) conduct performance evaluations to establish the validity of these models. Here we focus on the data needs, with only passing reference to model development/mountain meteorology research and performance evaluation needs.

In order to utilize models, we will need to improve quantification of the following:

A. Atmospheric emissions of various chemicals

1. Pollutants for which NAAQS's have been established: SO₂, PM, CO, O₃, Pb, NO, NMHC.
2. Currently unregulated pollutants: silica, other sulfur compounds, metals, CO₂, NH₃, trace organics, trace elements (e.g., Be, Hg, asbestos, F), and respirable particles and anything else identified as possibly contributing to an adverse AQRV impact.

B. Emissions on the basis of facility unit operations (emission factors)

1. Mining: silica, salts, mercury, lead, methane, CO, NO_x, HC, PM, fugitive dust.
2. Storage, transport, and crushing of oil shale: PM, CO, NO_x, SO₂, HC, silica, fugitive dust.
3. Retorting technologies: SO₂, H₂S, COS, NO_x, HC, CO, POM, PM, trace elements

and heavy metals (i.e., antimony, arsenic, beryllium, boron, copper, fluorine, lead, mercury, nickel, selenium, zinc, cobalt, molybdenum, chromium, iron).

4. Upgrading, refining, gas cleaning, and power generation: CS₂, COS, SO₂, H₂S, NH₃, HC, NO_x, fly ash.
5. Handling and disposal of raw and retorted shale: fugitive dust, POM.
6. Community growth, generally offsite, including space heating stationary sources, and mobile sources like automobiles and trucks: NO_x, PM, RHC, CO, POM.

C. Characteristic of the emission in detail

1. Locations of facilities and operations.
2. Size of activities, quantity and time histories of emitted material as a function of the type of process.
3. Local meteorological conditions: as a function of time and space, wind vector fields, atmospheric stability, topography, local precipitation, etc.
4. Physical parameters of the sources including temperature of effluent, velocity of effluent, stack heights, etc.
5. Background concentrations of air pollutants and chemical precursors.

D. Surface characteristics of areas where concentration estimates are required

1. Location and terrain features and surface details (forest canopy cover) of all target and receptor areas in relation to the source areas.
2. Terrain and surface conditions between the source and such target areas.
3. Location and air quality impacts from any other sources that may affect the target areas (contributions to the background pollutants of the target areas).

E. Meteorological conditions

1. Wind speed and direction fields through the zone of atmospheric transport from sources to target areas.
2. Routine release of radiosonde and/or pilot balloons at a sufficient number of locations within the development/transport area to characterize the synoptic climatology.
3. Atmospheric stability structure fields between sources to target areas.

4. Cloud cover and precipitation fields from sources to target areas.
5. Diurnal and seasonal variations of solar radiation and surface energy budget fields between sources and target areas.
6. Identification of any special or different local phenomena that might influence transport, dispersion, and removal.

In order to project dosages to the Flat Tops accurately, models must be able to account for physical processes that affect the concentration and dilution of pollutants. Some of the things that need to be considered are shown:

1. The characteristics of temperature inversions within the convective boundary layer, including their frequency of occurrence, extent, and nature, and the mechanisms by which they are formed and destroyed.
2. An understanding of how local valley circulations form, dissipate, and become coupled or decoupled from the synoptic-level flows.
3. An understanding of dry and wet deposition processes; in particular, the distribution of dosage as a function of forest canopy parameters such as tree sizes, spacing and densities, and species composition.
4. How simple a coupled meteorological/dispersion/deposition model can be to simulate adequately the transport, diffusion, and deposition of pollution from multiple sources to the Flat Tops Wilderness.

This list is by no means comprehensive, but it does point to some of the difficulties in modeling in the oil shale areas.

CONCLUSIONS

Current projections based upon reasonably high levels of oil shale production indicate that SD Class II increments as well as Class I increments will need to be carefully investigated for each proposed facility as well as for the totality of the development. Individual facilities will require careful planning and some strong emission control before the Class II increment will be met.

Unfortunately, there is no fully acceptable analysis of the actual impact, namely concentrations and dosages, on the Flat Tops Wilderness area as a result of oil shale development. This is a difficult problem that is only now beginning to receive attention. Complication is added not only by the recognized problems of dispersion

modeling on 100-km scales in mountainous topography, but also by equally difficult problems involving plume interaction with forested surfaces, and precipitation. Work is needed immediately to make preliminary identifications of pollutant concentrations and dosages likely to occur on the Flat Tops Wilderness as a result of the combination of industrial and community growth associated with the development of an oil shale industry in western Colorado. Of particular concern is the need to develop improved coordination among federal agencies and developers to conduct this work. The problem is larger than any one agency, leading us to conclude that such coordination is essential and should be a high priority.

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APPENDIX A

LIST OF ATTENDEES

Dr. James Bennett
Air Pollution Effects Specialist/Air Team
USDI/National Park Service
655 Parfet St.
P.O. Box 25287
Denver, CO 80225

Dr. James O. Blankenship
National Air Management Officer
USDA Forest Service
240 West Prospect Street
Ft. Collins, CO 80526

Dr. James Carson
Research Meteorologist
Argonne National Laboratories
9700 S. Cass
Argonne, IL 90439

Dr. Ronald L. Drake
Research Meteorologist
Battelle-Northwest Laboratory
Atmospheric Science Dept.
Box 999
Rickland, WA 99352

R. Scott Fifer
Hydrologist
USDA Forest Service
White River National Forest
Box 948
Glenwood Springs, CO 81601

Dr. Douglas G. Fox
Research Meteorologist
USDA Forest Service
Rocky Mountain Forest and
Range Experiment Station
240 West Prospect Street
Ft. Collins, CO 80526

Dennis Haddow
Regional Air Quality Specialist
USDA Forest Service
11177 W. 8th Avenue
Box 25127
Lakewood, CO 80225

Wendy M. Harrett
Ranger, Blanco District
USDA Forest Service
White River National Forest
Box 948
Glenwood Springs, CO 81601

Lee W. Jensen
Ranger, Yampa District
USDA Forest Service
Routt National Forest
Hunt Building
Steamboat Springs, CO 80477

Douglas A. Latimer
Air Quality Consultant
Systems Applications, Inc.
950 Northgate Drive
San Rafael, CA 94903

Dr. William Malm
Visibility Research Specialist/Air Team
USDI National Park Service
c/o Dept. of Atmospheric Sciences
Colorado State University
Fort Collins, CO 80523

Dr. William Lauenroth
Air Pollution Effects Specialist
Natural Resources Ecology Laboratory
and Range Sciences Dept.
Colorado State University
Fort Collins, CO 80523

James L. Mangan
Ranger, Rifle District
USDA Forest Service
White River National Forest
Box 948
Glenwood Springs, CO 81601

Dr. William E. Marlatt
Professor, Bioclimatology and Air Pollution
Department of Earth Resources
Colorado State University
Ft. Collins, CO 80523

Eric J. Martin
Landscape Architect
USDA Forest Service
White River National Forest
Box 948
Glenwood Springs, CO 81601

Robert J. Miller
Recreation Specialist
USDA Forest Service
White River National Forest
Box 948
Glenwood Springs, CO 81601

Dennis J. Murphy
Air Quality Researcher
Rocky Mountain Forest and Range
Experiment Station
240 West Prospect Street
Fort Collins, CO 80526

Dr. James Newman
Air Pollution Effects Consultant
Environmental Science and
Engineering, Inc.
Box 5
Gainsville, FL 32602

Robert H. Peterson
Botanist, Blanco District
USDA Forest Service
White River National Forest
Box 948
Glenwood Springs, CO 81601

Bernie Rios
Wildlife Biologist
USDA Forest Service
White River National Forest
Box 948
Glenwood Springs, CO 81601

Julie K. Sarazin
Wildlife Biologist, Rifle District
USDA Forest Service
White River National Forest
Box 948
Glenwood Springs, CO 81601

Dr. Kent R. Schreiber
Air Pollution Effects Specialist
USDI/Fish and Wildlife Air Pollution Effects
Eastern Energy and Land Use Team
Route 3, Box 44
Kearneysville, WV 25430

Dr. Lars Sohlt
Biologist
Environmental Impact Studies
Argonne National Laboratories
9700 S. Cass
Argonne, IL 90439

Larry D. Summers
Botanist, Blanco District
White River National Forest
Box 948
Glenwood Springs, CO 81601

Dr. John Turk
Limnologist
U.S. Geological Survey
WRD, Colorado District
Box 25046, MS415
Denver Federal System
Lakewood, CO 80225

Victor K. Weyers
Forester
USDA Forest Service
White River National Forest
Box 948
Glenwood Springs, CO 81601

Dr. Michael Williams
Air Quality Research Specialist
LASL, Group S-3, MS603
Las Alamos, NM 87545

APPENDIX B

ACRONYMS, ABBREVIATIONS, AND CHEMICALS

ACRONYMS

AAQS - Ambient Air Quality Standards
 PSD - Prevention of Significant Deterioration
 AQRV - Air Quality Related Values
 TSP - Total Suspended Particulates
 BACT - Best Available Control Technology
 EPA - Environmental Protection Agency
 RAWS - Remote Automated Weather Station
 SCS - Soil Conservation Service
 DOE - Department of Energy
 NAAQS - National Ambient Air Quality Standards
 ERT - Environmental Research and Technology, Inc.
 CBL - Convective Boundary Layer
 OTA - Office of Technology Assessment
 NE - North East
 RTP - Research Triangle Park, NC
 DRI - Denver Research Institute
 SAI - Systems Applications, Inc.
 LASL - Las Alamos Scientific Laboratory
 NCAQ - National Committee on Air Quality

ABBREVIATIONS

MW - Megawatt (10^6 watt)
 tds - total dissolved solids
 cfs - cubic feet per second
 m - meters
 km - kilometers

bpd - barrels per day
 mps - meters per second

CHEMICALS

S - Sulfur
 SO₂ - Sulfur dioxide
 O₃ - Ozone
 CO₃ - Carbonates
 HCO₃ - Bicarbonates
 CaCO₃ - Limestone
 B - Boron
 Mo - Molybdenum
 As - Arsenic
 P - Phosphorus
 N - Nitrogen
 F - Fluorine
 HC - Hydrocarbons
 PM - Particulate Matter
 CO - Carbon monoxide
 NO_x - Nitrogen oxides (NO, NO₂)
 POM - Polycyclic Organic Material
 NMHC - Non-methane hydrocarbons
 Pb - Lead
 SO_x - Sulfur oxides
 O_x - Oxidants
 pb - Lead
 NH₃ - Ammonium
 Be - Beryllium
 Hg - Mercury
 H₂S - Hydrogen sulfide
 COS - Carbonyl sulfide

Fox, Douglas G., Dennis J. Murphy, and Dennis Haddow. 1981. Air quality, oil shale, and wilderness--A workshop to identify and protect air quality related values of the Flat Tops. USDA Forest Service General Technical Report RM-91, 32 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

In January 1981, a workshop was conducted to discuss the potential impacts of oil shale developments on the air quality of western Colorado. Participants of the workshop included nationally recognized specialists in air quality modeling, in visibility, and in effects of air pollution on soil and water, fish and wildlife, and vegetation. The five working group reports that resulted outline an ambitious program of research necessary in order to protect the Flat Tops Wilderness. The workshop illustrates a general approach to the problem of identifying air quality related values. It is anticipated that this approach will prove useful to all federal land managers involved with Class I area protection.

Keywords: Air quality related values, air pollution, wilderness



Rocky
Mountains



Southwest



Great
Plains

U.S. Department of Agriculture
Forest Service

Rocky Mountain Forest and Range Experiment Station

The Rocky Mountain Station is one of eight regional experiment stations, plus the Forest Products Laboratory and the Washington Office Staff, that make up the Forest Service research organization.

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Research programs at the Rocky Mountain Station are coordinated with area universities and with other institutions. Many studies are conducted on a cooperative basis to accelerate solutions to problems involving range, water, wildlife and fish habitat, human and community development, timber, recreation, protection, and multiresource evaluation.

RESEARCH LOCATIONS

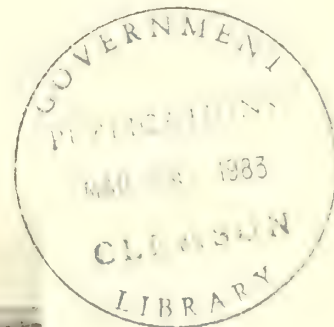
Research Work Units of the Rocky Mountain Station are operated in cooperation with universities in the following cities:

Albuquerque, New Mexico
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Flagstaff, Arizona
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Tempe, Arizona

*Station Headquarters: 240 W. Prospect St., Fort Collins, CO 80526

A Review of Uranium Spoil and Mill Tailings Revegetation in the Western United States

Teruo Yamamoto



General Technical Report RM-92
Rocky Mountain Forest and
Range Experiment Station
Forest Service
U.S. Department of Agriculture

PREFACE

This assessment of the uranium spoil and tailings problem was conducted to evaluate the revegetation aspects of reclamation. The assessment includes general inventory of mined lands and mill areas; characteristics of ores, tailings, spoils, and overburden; a review of current revegetation methodology and legal requirements; identification of additional research needed to develop new techniques; and health and safety considerations in the management of radioactive materials.

Data was obtained first by review of literature, particularly of the government documents section at South Dakota School of Mines and Technology, and by literature search using the USDA Forest Service WESTFORNET system. Second, information was obtained at professional meetings involving environmental activist groups and mining corporations, at seminars sponsored by the Union Carbide Company at the South Dakota School of Mines and Technology, and at the Second Symposium on Uranium Mill Tailings Management sponsored by the Civil Engineering Department, Colorado State University. Finally, recent field observations were evaluated for mining and milling operations in the southern Black Hills area, at Laguna and Grants, New Mexico, at Vitro tailings site, Salt Lake City, Utah, and from past field trips to Shirley Basin, near Casper, Wyoming.

ERRATA FOR

USDA Forest Service General Technical Report RM-92

A Review of Uranium Spoil and Mill Tailings
Revegetation in the Western United States

Teruo Yamamoto

On page 5, column 2, lines 17-19 should read:

indoor radon progeny levels (10 CFR 712 (Title 10, Code
of Federal Regulations, part 712), Grand Junction
Remedial Action Program).

On page 8, column 2, lines 7-9 below the equation should read:

on (1) the effect of chemical and radiological concentrations of raw tailings on the amount of root penetration into the tailings, and (2) . . .

A Review of Uranium Spoil and Mill Tailings Revegetation in the Western United States

**Teruo Yamamoto, Geologist
Rocky Mountain Forest and Range Experiment Station¹**

Abstract

The following aspects of uranium mine and mill tailings management are reviewed and discussed: (1) the history of the uranium remedial action program, (2) magnitude of the uranium spoils problem, (3) uranium deposits, mining, and milling, (4) status of reclamation, (5) problems in revegetation of uranium spoils and tailings, and (6) health and safety considerations.

¹*Headquarters is in Fort Collins, in cooperation with Colorado State University.*

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A Review of Uranium Spoil and Mill Tailings Revegetation in the Western United States

Teruo Yamamoto

MANAGEMENT IMPLICATIONS

The problems of reclaiming (via revegetation) uranium mill tailings piles and spoils are summarized as follows:

1. Reclamation acts in the western United States are relatively new. Consequently, there is little long-term experience with revegetation of uranium-mined (or of coal- and bentonite-mined) areas.
2. Uranium mill tailings piles are radioactive and contaminate the environment most commonly by wind and water erosion of radioactive particulates and by emission of radon gas and its progenies.
3. Indiscriminate revegetation programs create additional environmental problems, because plants absorb radionuclides and harmful trace elements and may pass them on to higher trophic levels within an ecosystem.
4. Plant growth and establishment are limited by climate and soil conditions. The problems of reclaiming abandoned piles and soils are greater because of the cost of overburden placement and lack of soil availability.
5. Revegetation may not provide long-term stabilization; instead, isolation and containment by rock cover may be the proper approach.

More information is needed on several aspects of revegetation in general:

1. Disturbed areas of mining activities, particularly the spoils and pits, must be appraised for their (1) radioactivity, (2) kind and depth of cover, (3) state of erosion, (4) degree and type of vegetative cover, and (5) status of radiological contamination.
2. Research has established that uptake of radionuclides and other contaminants are species dependent, but a great number of species need to be evaluated for their uptake characteristics.
3. Improved radiological safety and health procedures are needed in the revegetation program. Expertise developed by Argonne National Laboratory and U.S. Environmental Protection Agency (Office of Radiation Programs, Las Vegas Facility) will help to assess safety procedures.

Information is also needed on a site specific basis for the following aspects of revegetation:

1. The physical, chemical, and radiological properties of soil and soil substitutes (primarily overburden material) to be used as earth cover material and for control (from undisturbed areas surrounding the tailings piles), such as texture, water retention capacity, nutrient status, salinity-alkalinity, toxic trace elements, radionuclide concentration of natural uranium, thorium-230, radium-226, lead-210, and polonium-210.
2. The physical, chemical, nutrient, and radiological characteristics of tailings, such as texture, nutrient status, toxic trace elements; and radionuclide concentration of uranium-natural, thorium-230, radium-226, lead-210, and polonium-210.
3. The plant uptake of contaminants from earth covers over tailings not less than 3 m in depth, with less than $2 \text{ pCi} \cdot \text{m}^{-2} \cdot \text{s}^{-1}$ radon emission above background levels.
4. Availability of suitable soil and geologic cover materials. This kind of information is fundamental to revegetation of mill tailings piles and ponds.
5. The use of engineering methods to augment revegetation programs and help block radiation emissions. These methods are particularly important in quickly stabilizing abandoned mill tailings piles and in aiding quick revegetation.
6. Plant species which take up the least amount of radionuclides and other contaminants.
7. Contaminant levels of existing plants on tailings piles (such as what kinds of contaminants and how much uptake relative to tailings concentration, and areas of concentration within the plant).
8. Concentration levels of trace metals and radionuclides of plants growing on areas surrounding uranium tailings piles.
9. The effect of plant establishment on radon emission rates.
10. The uptake levels of radionuclides and other contaminants by animals inhabiting tailing piles, and their roles as vectors transporting radionuclides to the food chain.

INTRODUCTION

Wastes from uranium mining and mill operation—the contaminated spoils, heap-leached piles, and mill tailings—are radioactive and potentially hazardous. Spoils are overburden and other geologic materials removed in gaining access to the ore material. Heap-leached piles and mill tailings are mineral refuse from leaching and milling operations. If these materials are not stabilized properly they can contaminate the biosphere.

Uranium waste management in the past dealt primarily with the geological and hydrological aspects of the waste disposal systems (Whicker 1978), although by law, reclamation must include revegetation. Substantially less effort has been made to understand the biological aspects of tailing management, particularly the interaction of vegetation and animals with contaminated spoils and tailings. Indiscriminate revegetation programs can create additional environmental problems, because plants and animals are potential vectors for radioactive and other toxic chemical elements.

Literature on uranium spoil and tailings reclamation in terms of revegetation before 1978 in the United States is very scarce. However, studies by the Los Alamos National Laboratory on the vegetative stabilization of inactive uranium mill tailings piles (Dreesen et al. 1978, Kelley 1979, and Reynolds et al. 1978) present concepts useful in revegetation efforts.

MAGNITUDE OF THE URANIUM SPOILS PROBLEM—MINING LOCATIONS AND PRODUCTION IN THE UNITED STATES

Uranium ore has been milled in the United States since the late 1940's. Uranium mines have been operated in Alaska, Arizona, California, Colorado, Idaho, Montana, Nevada, New Mexico, North Dakota, Oregon, South Dakota, Texas, Utah, Washington, and Wyoming. From 1948 to 1974, 270,100 tons of U_3O_8 (yellowcake) have been produced from 116,962,000 tons of ore in the United States; 75% has come from the states of New Mexico and Wyoming, 45% and 30% respectively. The Colorado Plateau (fig. 1) accounts for 66% of the produced and known \$10 (cost per pound of U_3O_8) reserves. The Wyoming Basins account for 23% and all others 11% of the reserves (U.S. Environmental Protection Agency 1977).

The bulk of the \$15 and \$30 uranium reserves (as of 1977) are also found in the Colorado Plateau and Wyoming Basins. New Mexico and Wyoming, based upon production records, contain most of the \$15 and \$30 reserves (New Mexico 48%, Wyoming 37%, respectively).

As of January 1, 1976, 22,911,000 acres were held by the uranium industry for mining and exploration. Of this land, 44% was in Wyoming, 18% in Utah, 16% in New Mexico, and 7% in Colorado. The land held in the remaining states ranged from 4% in Arizona to 0.1% in

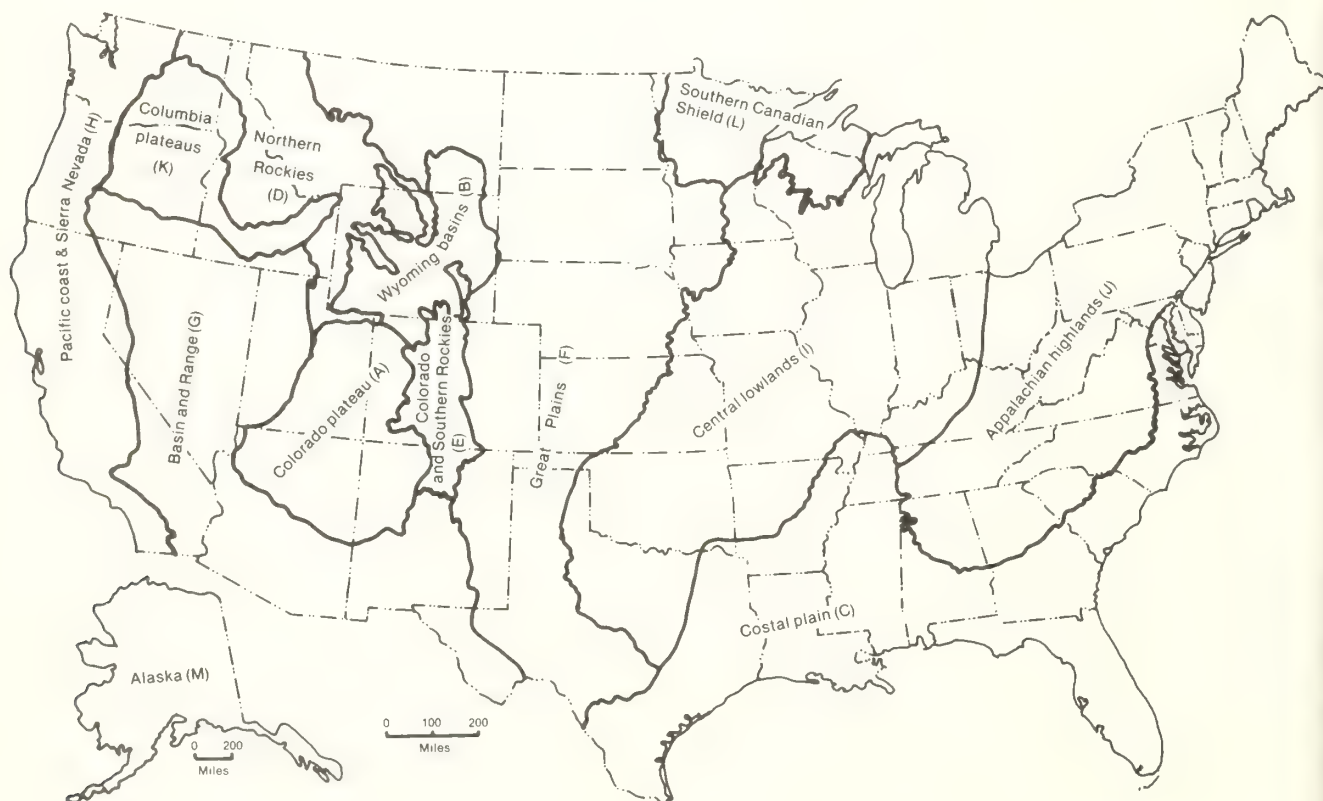


Figure 1.—Regional outlines used for the preliminary national uranium resources evaluation. (U.S. Energy Research and Development Administration 1976).

Oregon (U.S. Energy Research and Development Administration 1976). The most important uranium areas of the Western United States are shown in figure 2.

Mining Waste

Uranium ore is recovered by both open pit and underground mining. Pit mining produces the most waste because the overburden is stripped away. For example, in 1974, 2,666,000 tons of uranium ore were mined from open pits in Wyoming. The waste produced was 104,046,000 tons of overburden and 2,984,000 tons of mill tailings. In contrast, 1,216,000 tons of ore from underground mines in Colorado produced 1,210,000 tons of tailings (U.S. Environmental Protection Agency 1977).

According to the U.S. Environmental Protection Agency (1977), 93% of the declared daily milling capacity was centered in the states of New Mexico (48%), Wyoming (33%), Colorado (6%), and Utah (6%). From 1965, the uranium processing rates steadily increased while the grade of ore and the percent of U_3O_8 recovered declined from 0.23% to 0.163%. Thus, as lower grades of ore are mined, the tailings per pound of yellowcake increase. In 1976, it was estimated that

more than 9 million metric tons of tailings per year were put into tailing ponds by the domestic uranium industry. In addition, an equal or greater amount of waste milling solutions were also put into the ponds (Reed et al. 1976).

Inactive Uranium Mills

Inactive mill sites in the West, their priorities for remedial action, and quantity of tailings are shown in the Final Generic Environmental Impact Statement on Uranium Milling (U.S. Nuclear Regulatory Commission 1980a). Their present or former mill owners are shown in U.S. Environmental Protection Agency (1977). These sites, identified under the remedial action program of Public Law 95-604, are a guide to selecting areas of revegetation research, because mill tailing piles from these sites were deactivated before criteria on reclamation procedures were standardized. Consequently, most of these sites were inadequately stabilized.

Finally, inventory surveys are needed in forested areas and have been requested by forest land managers for information on aerial extent of uranium exploration and mining disturbance, nature of disturbance, chemical (including trace metal) and radiological

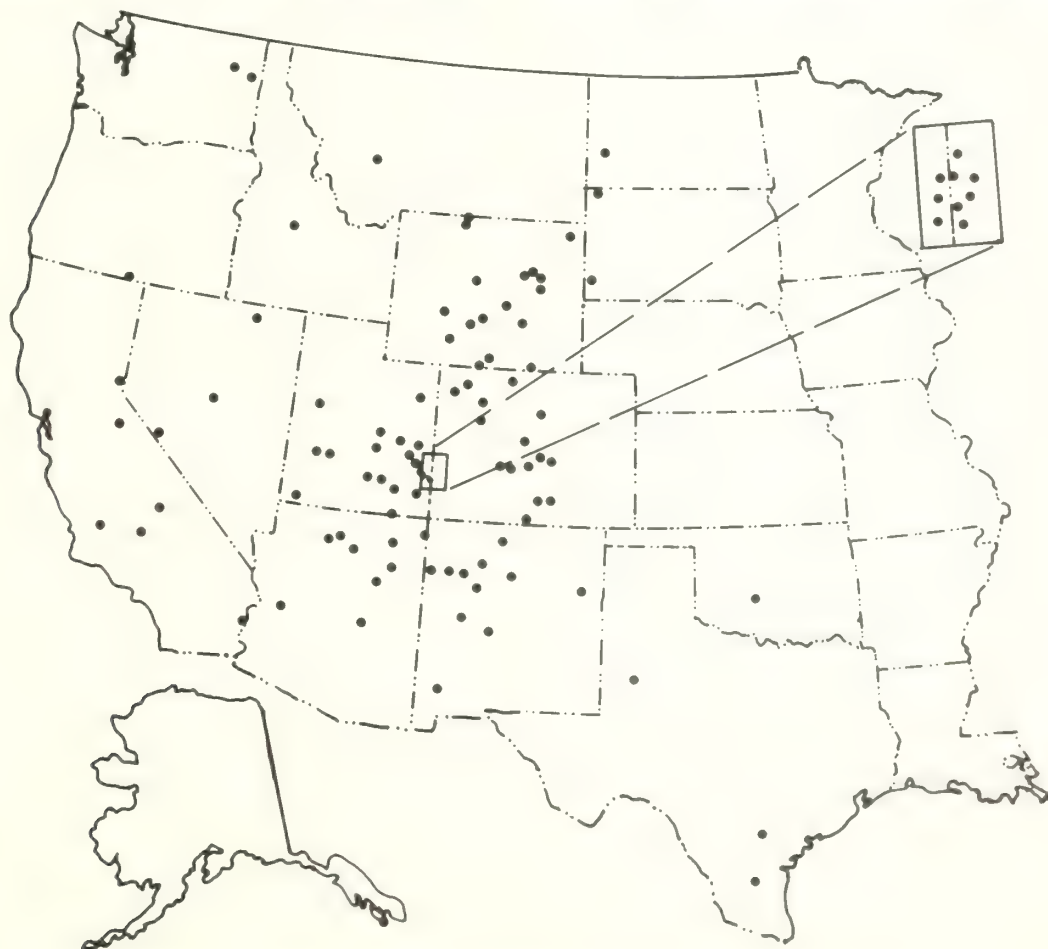


Figure 2.—Areas of uranium production in the western United States.
(U.S. Energy Research and Development Administration 1976).

properties of the spoils, possible contamination to the biota and hydrology, and the kinds of remedial actions needed.

CHARACTERISTICS OF DEPOSITS, MINING, AND TAILINGS

Sandstone Deposits

Most of the uranium deposits in the Colorado Plateau and adjoining districts are stream-laid lenses of sandstone, dominantly in the Chinle, Shinarump, and Morrison Formations. Uranium occurs as coatings on sand grains or as fillings on cement in interstitial spaces, where it has been deposited by water. The uranium content of the deposits is in the order of 0.05% to 0.25% U_3O_8 (U.S. Nuclear Regulatory Commission 1979a). Uranium deposits also occur in the Wind River Formations in Gas Hills and Shirley Basin area in Wyoming, Lakota Formation in the Black Hills of South Dakota and elsewhere in other formations in lesser amounts. The stratigraphy and lithology of the overburden and host rocks, which may be important in revegetation research, are described in the "National Uranium Resource Evaluation Preliminary Report" (U.S. Energy Research and Development Administration 1976).

In general, the ore was formed by groundwater solutions that moved down the dip by gravity to a reducing environment, where the uranium was precipitated out of solution. These deposits are tabular or lenticular layers (pods), and deviations have the cross-section form of an erect crescent known as rolls. Because it is an extremely active material, uranium combines or is associated with many different compounds—sulphates, phosphates, vanadates, arsenical compounds, and carbonates (Reed et al. 1976, May 1973). In addition, uranium commonly occurs with carbonaceous matter (Dreesen et al. 1978) and many trace elements—selenium, molybdenum, lead, zinc, cobalt, nickel, copper, and others (Cannon 1962, Dreesen et al. 1978, Merritt 1971).

Mining

Although in 1976, underground mining contributed roughly 49% of the total uranium ore produced in the United States,² many of these mines resulted from open pit mines that followed the major deposits underground. The ore bodies vary greatly in size from those containing only a few tons to those hundreds of meters across and containing millions of tons of ore. In the Shirley Basin area and the southern part of the Powder River Basin, Wyoming, and in the Ambrosia Lake District, New Mexico, groups of ore bodies and the in-

tervening, thinner, mineralized zone extend intermittently from 8 to 10 km (Butler 1972).

Surface (open pit) mining may be done to depths of more than 150 m, whereas underground mining takes place at depths below 90 m (Reed et al. 1976). As in current coal strip mining, the surface soil is presumably stockpiled, if available, for later reclamation. Overburden from the initial excavation is placed on the surface and later used to backfill where mining has been completed. But, in most instances, the mined-out pits are so huge that it is not economically feasible to refill such holes (Schilling 1971). Thus, large amounts of material must be handled in mining and initial processing operations.

Milling and Tailings Disposal

The ore is prepared in the mill by crushing, grinding, and blending. Sulfuric acid (H_2SO_4) is used in the leaching process. To oxidize the reduced uranium minerals, reagents such as MnO_2 and $NaClO_3$ are added, although aeration is often sufficient. Carbonate leaching is used when the carbonate content of the ore and its buffering capacity are so high that acid consumption would be prohibitive. Many purification processes are used to purify and concentrate yellowcake; during this process molybdenum, vanadium, selenium, iron, lead, nickel, zinc, cobalt, and many other impurities are removed and redistributed. The resulting tailings are highly mineralized. Finally, when radium-226 is separated from uranium, about 98.0% to 99.8% of the radium contained in the ore ends up in the tailings in solid form. Tailings consist of 80% sand and 20% slimes. The latter carry the bulk of the radium (Misa 1976; Moffett and Tellier 1977, 1978). There are naturally occurring isotopes of uranium; because uranium-238 has a natural abundance of 99.283%, this isotope and its decay products are of prime concern in the tailings (Moffett and Tellier 1977). The important radioisotopes in terms of plant uptake are those which have a significant half-life in relation to the growing season of the plants. These radioisotopes are uranium-238, uranium-234, thorium-230, radium-226, lead-210, and polonium-210. The tailings also emit radioactive gas, radon-222, which can be transported long distances. The size of tailings piles reported and observed near Grants, N. Mex. may commonly vary from 2 to 37 ha (Dreesen et al. 1978); one active tailings pile had an average height in excess of 35 m and an area perhaps exceeding 60 ha.

The radon emanation from the decay of radium-226 in the tailings and other radioactive emissions create a long-term radiation risk which necessitates the definition of source terms for the tailings pile. Source terms are defined as the quantity of radioactivity (in curies, for example) released in a specified period of time (U.S. Nuclear Regulatory Commission 1979b). For example, if the average radium concentration is known, the external gamma exposure rate over the tailings pile can be estimated. The radon emanation rate can also be estimated (Schiager 1974), and the depth of overburden

²Klemenic, J. 1976. *Analysis and trends in uranium supply*. Presented at the Grand Junction Office Uranium Office Industry Seminar (October 19-20). U.S. Energy Research and Development Administration.

necessary to reduce gamma and radon emanations can be estimated. Dreesen et al. (1978) emphasized the importance of recognizing source term variations due to distribution and variations in physical, chemical, and radiological properties of sand and slime of the tailings pile and overburden.

The current practice of discharging excess liquids from tailings ponds into drainages and injecting them into deep wells represents major environmental impacts (Reed et al. 1976, Kaufmann et al. 1976). If the hydrogeological, engineering, radiological protection, environmental, and economic aspects are favorable, disposal of tailings to mined-out portions of a mine is preferred. There is some promise for this method if the whole operation is planned in advance. However, there are difficulties. First, it is costly. Second, sands are satisfactory for backfill but the slimes are not. Third, slimes are more radioactive and contaminate hydrogeological systems. Fourth, if only slimes are retained in the tailings ponds, the structural and agricultural properties are not as good as the original tailings. This leads to a greater likelihood of waste retention system failure and a more difficult revegetation problem (International Atomic Energy Agency 1976).

DEVELOPMENT AND STATUS OF RECLAMATION EFFORTS

Surface uranium-mined lands in the West have not been as extensively reclaimed as coal-mined lands. As recently as 1977, reclamation was limited to New Mexico and Wyoming (Evans et al. 1978). Furthermore, mining industry and government agency publications generally do not provide sufficient detailed information about the ecological aspects of mining disturbances.

In the United States, most of the uranium ore mined from the early 1940's through 1970 was processed for the Manhattan Engineering District and the Atomic Energy Commission (predecessor of the Energy Research and Development Administration) by private companies. When processing operations ceased for the U.S. Government, tons of uranium mill tailings remained. Mill operators were not aware of the potential radiation hazards to the public from exposure to the mill tailings. At that time, the general consensus was that the effects of the radioactivity on the public were minimal (U.S. Department of Energy 1979). Nevertheless, the possibility of health hazard from long-term exposure from windblown and water-transported tailings material were suspected.³ Some companies made an attempt to stabilize the tailings after operations ceased, while others did so with varying degrees of success (Ford, Bacon and Davis Utah Inc. 1977h).

Until 1977, published studies on radiation levels on land in the vicinity of inactive processing and mill tailings sites generally were limited in scope. A report by

Eadie et al. (1976) of outdoor radon air concentrations, radium-226 concentrations in the soil, and gamma exposure rates in the vicinity of uranium mines and mills throughout the Ambrosia Lake area in New Mexico indicated concentrations in excess of typical background levels. A better definition of background levels and a more thorough evaluation of specific source terms in the immediate Ambrosia Lake areas were suggested.

Similarly, gamma scan measurements on inactive uranium mill sites near Riverton, Wyo. (Douglas 1977) showed contamination above background levels at adjacent areas, presumably caused by wind erosion. However, results of limited well water and working level samples near the site did not exceed EPA's drinking water standard (U.S. Environmental Protection Agency 1976) or the Surgeon General's guidelines for indoor radon progeny levels (10 CFR 712 (Vol. 10, Code of Federal Regulations, page 712), Grand Junction Remedial Action Program).

In 1974 the Atomic Energy Commission recommended a generic and comprehensive study of all formerly active uranium mill tailings sites. Detailed engineering evaluations of many of these sites have been issued in a series of reports prepared by Ford, Bacon and Davis Utah Inc. (1976, 1977a-r inclusive, 1978) for the Energy Research and Development Administration. The reports include gamma surveys, radon concentration measurements, and measurements determining the extent of windblown soil, ground and surface water contamination. These surveys, in addition to radiological characterization, provide the following kinds of information which are pertinent to revegetation research: (1) present condition of the site, such as size of tailings pile, (2) whether the site is nonstabilized or stabilized, perhaps with earth cover, riprap, or grass cover, (3) tailings and soil characteristics, and (4) geology, hydrology, meteorology. In addition, Oak Ridge National Laboratory prepared a series of reports summarizing the radiological survey performed at these sites as a part of the assessments. Four from these series of reports are cited (Haywood et al. 1979, 1980a-c).

As a result of these surveys, Public Law 95-604, Uranium Mill Tailings Radiation Control Act of 1978, was enacted on November 8, 1978 (U.S. Department of Energy 1979). The law provides a program under Department of Energy to regulate uranium or thorium mill tailings processed at active and inactive operations to stabilize and control tailings in a safe and environmentally sound manner and to minimize or eliminate radiation hazards to the public.

Some of the rules pertinent to revegetation research on active and inactive uranium mill tailings piles as stated in 45 FR 65521 (Vol. 45, Federal Register, page 65521) are as follows:

1. Sufficient earth cover, not less than 3 m, should be placed over tailings to reduce radon exhalation from buried tailings to a calculated value of not more than $2 \text{ pCi} \cdot \text{m}^{-2} \cdot \text{s}^{-1}$ above natural background levels.

³U.S. Atomic Energy Commission. 1963. A report of the Monticello mill tailing erosion control project, Monticello, Utah. Report No. RMO 3005, 31 p. U.S. Atomic Energy Commission, Grand Junction, Colo. Office

2. A full, self-sustaining, vegetative cover should be established on the earth cover or a rock cover should be used to reduce to negligible amounts the potential for significant wind and water erosion of the earth cover.
3. In arid and semiarid regions, where it is unlikely vegetation will be full and self-sustaining, rock cover stabilization is mandatory.
4. Topographic features should provide good wind protection.
5. Embankment and cover slopes should be relatively flat after stabilization. Specific limits on final embankment slopes are not identified, however.

More recently Environmental Protection Agency's 40 CFR 192 (46 FR 2526, January 9, 1981), Proposed Disposal Standards for Inactive Uranium Processing Sites, Invitation for Comment, proposes an allowed tailings emission rate of $2 \text{ pCi}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ with soil cover recommended. No specific soil depth is specified. Also, a radium-226 concentration not exceeding 5 pCi/g in the earth cover 1 foot of surface, or in any 15 cm thickness below 1 foot, is specified (10 CFR 192, 45 FR 27367, April 28, 1980). Further, there are no formal regulations concerning disposal of mill tailings (U.S. Nuclear Regulatory Commission 1980b). The Environmental Protection Agency and Nuclear Regulatory Commission standards seem to be interim pending public review and promulgation of final standards.

Revegetation research on uranium mill tailings has only recently begun on some commercially owned operations (Reynolds et al. 1978, Dreesen et al. 1978, Kelley 1979) and on some Tennessee Valley Authority (1976, 1978, 1979) sites.

Unlike reclamation of surface mined lands, reclamation for underground operations must be delayed until normal mining operations cease because of the nature of the operations, the semipermanent nature of the structures involved, and the constant addition of material to the waste piles (Tennessee Valley Authority 1976). Reclamation may be further delayed by the dramatic climb in the price of uranium from \$6 a pound in 1973 to \$42 a pound since 1977, which has encouraged mining lower grade ores and reprocessing earlier discarded tailings. This rise in uranium price has delayed reclamation in Wyoming (Evans et al. 1978) and possibly in other states as well.

The U.S. Nuclear Regulatory Commission (1980a, 1980b, 1980c), in its environmental impact statement, did not address uranium mining impacts (e.g., nature of spoils and disturbance of land) because such an inclusion would have resulted in significant delay of improvements in current regulatory programs with respect to uranium milling. However, the U.S. Environmental Protection Agency, under the provisions of Public Law 95-604, is preparing a report on the environmental hazards of uranium mine wastes (U.S. Nuclear Regulatory Commission 1980b). Similarly, acceptable chemical concentration levels of plants grown on earth cover emplaced over uranium tailings piles are not proposed in the U.S. Nuclear Regulatory Commission's Final Generic Environmental Impact State-

ment (1980a) or specified in Appendix A of 10 CFR 40 (45 FR 65521, October 3, 1980). However, the overall guiding principle in selecting required levels of tailings isolation is to return the tailings site to a condition reasonably near those of surrounding environs (U.S. Nuclear Regulatory Commission 1980a, 1980c).

PROBLEMS IN REVEGETATION OF URANIUM SPOILS AND TAILINGS

Revegetation of uranium mine spoils and tailings in the western United States must consider problems associated with (1) site characteristics, (2) compensating for climatic conditions, (3) spoils revegetation, (4) erosion, (5) biological interactions—penetration and uptake of contaminants by vegetation and animals, (6) tailings revegetation and cover, (7) riprap cover, (8) plant selection, and (9) shaping and sloping.

As in coal-mined land reclamation, the objectives of revegetation are to prevent erosion and to establish a sustainable ecosystem. But in terms of long-term disposal for 1,000 years, for example, uranium mine and mill waste may require isolation and containment, not revegetation (Dreesen et al. 1978, U.S. Nuclear Regulatory Commission 1980a).

Site Characteristics

Although each area has its own characteristics, the arid, sandy plains and basins of the Colorado Plateau and Wyoming typify the conditions found at uranium-mined lands in the West. The sedimentary deposits where uranium is found most often are at lower elevation sandy plains, basins, or plateaus. Surface soils are usually poorly developed in both physical and chemical properties, are shallow, and have all the problems found in revegetating and reclaiming coal strip mine spoils (i.e., limited moisture, salinity, alkalinity, acidity, toxic constituents, deficiency of nitrogen and/or phosphorus, blowing sand, and animal browsing and grazing) (Kelley 1979, National Academy of Sciences 1974).

Compensating for Climatic Limitations

The prevailing climate creates an undependable supply of moisture for revegetation. On the Colorado Plateau, annual precipitation ranges from 12.7 cm in the deserts to 45.7 cm at high altitudes (Cannon 1962); a range of 18 to 25 cm is reported (May 1973) for mining areas in the western United States. The areas are subjected to high evaporation and sublimation losses, high temperatures, and desiccating winds. Surface and ground water supplies generally are not available. Because uranium and coal occur in the same areas (Evans et al. 1978) revegetation techniques for coal-mined areas which deal with the problems of moisture supply (USDA Forest Service 1979a, 1979b) should apply to uranium areas.

Treatments that augment water infiltration, and moisture retention and detention should noticeably improve revegetation programs. Well-known range improvement practices such as surface pitting, mulching with wood chips, straw, asphalt materials, and snow fencing may be employed with varying degrees of success because water is limited in many uranium areas.

Irrigation may be an impractical method of promoting revegetation. More important, the cessation of irrigation often resulted in extensive mortality of established vegetation and promoted the upward movement of radioactive elements and other potentially toxic elements such as selenium and molybdenum (Dreesen et al. 1978, Markos 1979). Further, pitted surfaces, water harvesting trenches, and other water collection structures may become collective centers of radioactive, alkali, and other salts similar to those seen in saline-alkali areas of bentonite and coal deposits (Sandoval and Gould 1978). Hence, one of the major goals of vegetational stabilization studies may have to be the determination of environmental factors harmful to establishing vegetation without irrigation (Dreesen et al. 1978, Kelley 1979).

Spoils Revegetation

From a geographical, ecological, or geological standpoint, the revegetation of uncontaminated uranium mine spoils should not pose problems unusually different from coal mine spoils. The problems are site specific and usually can be resolved by selective emplacement of top soils and overburden (Dreesen et al. 1978, Kelley 1979, Reynolds et al. 1978).

Uranium spoils samples from each site must be analyzed to determine mineralogy, nutrient status, texture, and pH, before revegetation can begin. The same techniques for dealing with physical and chemical characteristics of coal spoils can be used for uranium spoils (USDA Forest Service 1979b, Schaller and Sutton 1978). However, if the spoils are contaminated with radionuclides and their progenies or with potentially toxic trace elements, in greater amounts than those found in adjoining lands, these materials must be handled and treated in the same manner as mill tailings and analyzed for these contaminants at appropriate laboratories. Vegetation on contaminated spoil piles possibly could absorb these elements at levels toxic to grazing animals or could present a public health problem similar to tailings piles. However, unless the spoils are contaminated by radioactivity or chemically toxic elements, priority should be given to research on mill tailings waste.

Erosion

Erosion by wind and water must first be stabilized before revegetation can begin. Wind and water erosion are obvious in uranium waste areas where maintenance has been discontinued (U.S. Environmental Protection Agency 1973, Douglas 1977). There is extensive literature on wind and water erosion.

Studies on wind erosion by Chepil (1945) are classics. Erosion protection measures for western coal-mined land reclamation are summarized by Verma and Thames (1978). Thames et al. (1974) measured runoff from a disturbed, coal-mined watershed in Arizona. Runoff and erosion characteristics from disturbed coal-mined land were estimated from simulated plot studies in North Dakota by Gilley et al. (1977), and in Wyoming by Lusby and Toy (1976). Similarly, infiltration studies on coal spoils were reported by Farmer and Richardson (1976), Rahn (1975), and Yamamoto (1979). However, these findings are based on research done on experimental areas or using scale models. No data are available on actual disturbed coal-mined lands or uranium mill tailings and spoil piles.

Available information on the movement and characteristics of radioactive elements of airborne particles is increasing (Breslin and Glauberman 1970, Kalkwarf 1979, Eadie et al. 1976, Douglas 1977, Travis et al. 1979). As more data and knowledge are accumulated for wind erosion, more research is also needed on plant-slope stability relationships because mine-waste embankments have a history of instability (USDA Forest Service 1979c).

Technology to control sheet and rill erosion is already available. For example, Abt and Ruff (1978) suggested using the Universal Soil Loss Equation to control or eliminate excessive losses from water erosion after mining is completed. Similarly, the Wind Soil Loss Equation (Utah Water Research Laboratory 1976) also can be used, because the same practices used to control water erosion will also control wind erosion and vice versa (Shepherd and Nelson 1978). These equations developed for agricultural and highway lands respectively may not consistently predict mine spoil losses (Gee et al. 1978), but they represent the current state-of-the-art and contain general principles that should apply to all sites.

Biological Interactions—Penetration and Uptake of Contaminants by Vegetation and Animals

More information and research are needed to assess interactions of plants and animals with uranium mill tailings or contaminated spoils over an extended period of time. Whicker (1978) emphasized the role of plants and animals in the long-term erosion process and the penetration and uptake of radionuclides by biota on uranium tailings piles.

Dreesen et al. (1978) discussed the potential contaminants associated with uranium mill tailings and stressed the significance of contaminant uptake by plants to the food chain. They also questioned the duration of plant cover over long periods of time and suggested the use of riprap cover to augment the vegetation cover.

Effects of Plants and Animals on Erosion of Tailings Piles

Current reclamation plans for radioactive uranium tailings must provide sufficient earth cover, not less

than 3 m deep, to reduce direct gamma radiation to essentially background levels and radon emanation to less than 2 pCi·m⁻²·s⁻¹ above natural background levels (10 CFR 40, 150 in 45 FR 65521, Oct. 3, 1980). The current practice is to cover the tailing surface with a layer of clay, followed by overburden, then topsoil covered with planted/seeded vegetation (Scarano and Linehan 1978). However, vegetation does not necessarily assure long-term stability. Subtle changes in soil and vegetation caused by animals could affect the long-term soil dynamics (Whicker 1978). For example, heavy grazing by cattle, in the natural pastures of short-grass plains of north-central Colorado, may be causing the loss of about 30.5 cm of surface soil in 1,000 years (Alldredge and Whicker 1972). Under a light grazing regime, net soil accumulations of about 35.6 cm per 1,000 years were suggested in adjacent pastures—a net difference of about 66.1 cm of soil between the two types of grazing. These changes may well influence plant survival and vigor.

Plants and animals, particularly burrowing animals, generally cause pulverization, granulation, and transfer of large amounts of soil. Termites, for example, are reported to have a beneficial effect on the development of strip-mine spoils (Ettershank et al. 1978). Similarly, the action of microbiological organisms on plant growth need to be examined (Lindsey et al. 1977). Also the amount of soil transported to the surface by ants (Uresk and Cline 1978) and gophers (Ellison 1946, Seton 1929) may affect erosion. Rodents and plants can also reduce soil water potentials significantly (Soholt et al. 1976). Also, mule deer (Arthur and Alldredge 1979) and cattle (Wijk and Braams 1960) probably ingest significant amounts of soil over time. Finally, rodents, ungulates, and insects often severely consume and destroy newly planted vegetation so as to nullify revegetation attempts.

Proper consideration should be given to these complex ecological interactions that may have profound long-term effects on stability of protective covers. Soil and vegetation can be protected using control measures, such as fencing, repellants, use of less palatable species (USDA Forest Service 1979a, 1979b). However, more data and experience are needed to determine performance standards such as erosion rates and the time needed to adequately monitor the sites after mining.

Biological Penetration, Uptake, and Transport of Contaminants from Tailings Piles

Studies by Dreesen et al. (1978), Moffett and Tellier (1977), Vavilox et al. (1977), Cataldo et al. (1977), Ford, Bacon and Davis Utah Inc. (1978), and others have established that plant root penetration into the spoils and tailings, and uptake of radionuclides and other toxic chemical elements, particularly from covered and/or uncovered tailings piles and ponds, may constitute a significant food chain transport mechanism.

The uptake of radionuclides and trace elements has been examined to determine if these elements are

being concentrated in plants above background levels (Dreesen et al. 1978, Moffett and Tellier 1977, Rickard et al. 1977). However, the mechanism of plant uptake of contaminants mixed into the spoil is probably different from uptake by plants or overburden placed over a tailings surface. The magnitude of uptake is usually expressed by the concentration ratio (CR):

$$CR = \frac{\text{Ci/g dry weight plant material}}{\text{Ci/g dry weight soil}}$$

Uranium amended (uranyl nitrate) lysimeter experiments at Hanford repository have shown, for example, that uranium concentration in plant materials appear to vary independently of soil concentration (Rickard et al. 1977). But more data utilizing actual uranium mill tailings are needed. Moreover, information is needed on (1) the effect of chemical and radiological concentrations on the amount of root penetration into the tailings of raw tailings, and (2) effect of overburden or soil depth on plant root penetration into the tailings and uptake of contaminants. Further, detailed information on trace metal and radionuclide concentrations in plants growing on lands adjoining the tailings pile areas is essential to determine acceptable levels of chemical constituents of plants growing over tailings piles.

Further studies are needed to examine soil-to-root pathway, foliar pathways (Romney et al. 1973), and surface contamination. Studies of influences on plant uptake (Cataldo et al. 1977) indicate that uptake is dependent on the plant species (Dreesen et al. 1978). The reasons for this variability need to be thoroughly investigated. Previous geobotanical work must also be reviewed. For example, the absorption characteristics of *Astragalus* vary considerably in associated selenium absorption (Cannon 1962). Studies at Rockwell Hanford Operations by Battelle Pacific Northwest Laboratories (Cataldo et al. 1977, Schreckhise et al. 1979, Cline and Uresk 1977) indicate that the uptake characteristics of cheatgrass (*Bromus tectorum*) and Russian thistle (*Salsola kali*) need further study. Cheatgrass is an early season competitor for soil moisture and nutrients; therefore, a good stand of cheatgrass is able to reduce the amount of deep-rooted Russian thistle that germinates later in the year (Cline and Uresk 1979). Also, Markos (1979) suggests that more geochemical studies of the identity, quantity, and profile distribution of salts and radionuclides are needed in conjunction with plant uptake investigations. The possible hazards posed by toxic trace elements (U, V, Mo, Se, As, Pb, Cu, Ni, Co, Zn) enriched in tailings should not be ignored (Dreesen et al. 1978, Merritt 1971). Molybdenum poisoning has been diagnosed in cattle grazing near uranium mines in Texas (Dollahite et al. 1972), and uranium mills in North Dakota (State of North Dakota 1978) and Colorado (Chappel 1975). Mortality of sheep, grazing in a uranium ore outcrop area in New Mexico, has been tentatively linked to selenium toxicity (Rapaport 1963). Forage plants containing high selenium concentrations can cause chronic selenium poisoning in two forms—blind staggers and alkali

disease. Plants with extremely high selenium concentration can cause acute selenium poisoning (Rosenfield and Beath 1964).

Because element concentrations in plant tissues may change with plant age (Johansen 1978, Cataldo et al. 1977) changes in sampling schemes and protective measures may be necessary. Also, data on the area of concentration within the plant (stem, foliage, roots, seeds) of radionuclides and other toxic chemicals are needed to help understand the food chain cycling process (Schreckhise and Cline 1980). The effect of vegetation on radon exhalation has not been demonstrated clearly, either. For example, vacant root channels or root penetrations could provide additional pathways for radon diffusion to the surface (Wullstein 1978).

Some plant species may even provide a means for monitoring nuclear plant sites or mill wastes for chronically emitted amounts of low-level, ionizing radiation. Research by Campbell and Rechel (1979) on somatic mutations in relation to reproductive integrity and pollen viability of *Tradescantia* suggests that such an alternative is possible.

The presence of carbonaceous matter has been reported in many uranium ore deposits (Squyres, 1970; Granger, 1963). These organic constituents may complex trace metals dissolved from tailings or originally may contain the trace elements in the ore matrix that dissolved after milling. Such organo-metallic species may play a significant role in the transport, uptake, and toxicity of trace elements from mill tailings (Dreesen et al. 1978). Further, the action of microbes in tailings may form volatile organo-metallic species (Wood, 1974). Because organic materials appear to have a key role in the enrichment of trace elements in ores, it should be expected that these organic constituents could significantly influence the release of trace elements from tailings.

Prairie dog mounds and rabbit and coyote droppings have been observed at tailings sites. Animal use of these sites indicates that studies are needed on the role of burrowing and other animals in (1) radon diffusion and (2) the uptake and transport of radionuclides (Rogers and Rickard 1977). Studies must evaluate the radioactive levels of animals inhabiting radioactive waste areas and their role as vectors transporting radionuclides to people (Schreckhise et al. 1979).

Tailings Revegetation and Cover

The most practical and effective means of promoting vegetation and blocking the release of radioactive particulates and radon is to cover the tailings with earth. A minimum cover thickness of 3 m is specified by Appendix A of 10 CFR 40. According to U.S. Nuclear Regulatory Commission (1980c), this depth of cover is believed to provide a long enough diffusion path so that substantial amounts of radon and its solid daughters can be made to decay before escaping to the surface. But there are many uncertainties about long-term (i.e. 1,000 years) cover protection. The U.S. Nuclear Regula-

tory Commission believes that the minimum cover requirement provides a desirable margin of physical isolation of the tailings in the face of these uncertainties and will avoid undue reliance on special materials or maintenance of special conditions (U.S. Nuclear Regulatory Commission 1980a).

Judgment and experience are required to evaluate the many properties (including soil properties, emanating power, and vegetation cover) controlling radon exhalation from earth cover materials (U.S. Nuclear Regulatory Commission 1980a, 1980c). Moreover, the rules for tailings disposal are not final, and the cost of overburden placement over tailings is very expensive. Much research has gone into a search for cover material technologies that are economical, effective, and reduce the thickness of cover required. Three meters of earth cover may not be sufficient to reduce radon exhalation to $2 \text{ pCi}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ on a site specific basis. Further, revegetation cover and density is seldom as complete or permanent as desired. Therefore, engineering, chemical, or other treatments should be used to effectively complement the earth cover. Several different treatments on tailings are possible.

No Cover: No Soil Amendments, No Irrigation

In the arid to semiarid regions of the Southwest and the northern Great Plains, only a sparse growth of invading species is likely to become established if no artificial revegetation techniques are used (Dreesen et al. 1978, U.S. Environmental Protection Agency 1973).

Aridity, high salts concentration, and extremely low pH (or, conversely, extremely high pH resulting from chemical treatment of the ore) will hinder plant establishment and growth. The tailings will be subject to wind and water erosion.⁴

No Cover: Seeding, Soil Amendment, Irrigation

At Edgemont, S. Dak., two tailings plots were neutralized with lime application, fertilized with manure and ammonium nitrate, and seeded with rye grass, red clover, and a species known locally as fireweed (U.S. Environmental Protection Agency 1973). One plot was watered by a sprinkler system once every three days (amount of water used was not reported); the other plot was not watered. Aside from site stabilization, the consequences of plant uptake of radioactive materials was not considered at that time.

Revegetation failed on both plots. It was believed that the lack of good soil base and the late planting date caused the failures. However, fireweed, although

⁴Abandoned (and some active) tailings and mill area spoils in the plains observed in New Mexico and South Dakota were dustier than those observed in the forested uplands. However, an abandoned tailings bench in the uplands of Mount Taylor District in Grants, New Mexico, showed very little sign of erosion even without any vegetation cover. No dust was observed, even under very windy conditions, from the porous sandy loam surface which showed very little sign of compaction. (Personal observation by the author.)

sparse, did germinate on both plots. The fact that fireweed could grow was considered positive, because fireweed could provide a mulch source for the establishment of natural grass.

Generally, irrigation with soil amendment is expected to enhance establishment of vegetation, because toxic materials are leached from the soil. However, plant communities established by irrigation may not survive once irrigation is stopped. Moreover, irrigation may increase salt accumulation, especially in arid regions (Thorne and Peterson 1949).

No Cover: Seeding, Soil Amendment, Wet Climate

In wet, temperate areas, such as at Elliot Lake, Ontario, species of grass, legumes, and annuals were seeded and successfully established by neutralizing acidity and adding fertilizer to compensate for the low nutrient status of the tailings (Murray and Moffett 1977). No supplemental organic matter or topsoil were involved. Moffett and Tellier's (1977) study on the uptake of radioisotopes by creeping red fescue (*Festuca rubra* L.), reed canary grass (*Phalaris arundinacea* L.), redtop (*Agrostis alba* L.), and timothy (*Phleum pratensis* L.) showed that uranium and radium-226 concentrations were higher in the grasses from the tailings than those from the control (potting soil). The uranium concentration of 0.030 mg/g, from the tailings in grass tissue, was not considered a hazard to any life form because of uranium's low specific activity. Specific activity is defined as the number of curies or the concentration of radioactivity per unit of mass or volume (Cember 1969). In contrast, the concentration of radium-226 in grass tissue (5.48 pCi/g) from tailing's was more than 20 times the concentration found in grass tissue (0.24 pCi/g) from the potting soil control. Radium-226 has an extremely high specific activity and, therefore, a very low maximum permissible concentration, for example, in water. Nevertheless, the concentration ratio of radium-226 for grass grown on tailings was 0.03, a value considered as biologically insignificant.

Shallow Soil Cover

The term shallow soil cover is defined in this report as any soil or earth cover less than 1 m deep. As required by law, covering the tailings with surface soil (stockpiled during initial mining activities) still seems to be the most practical way to obtain a suitable growth medium. However, sandstone overburden materials with fairly high infiltration rates and good water retention (sandy clay loam and clay loam) were also favorable for plant establishment (Dreesen et al. 1978, Reynolds et al. 1978, Kelley 1979). These moderately coarse textured soils also had favorable nutrient concentrations. However, without supplementary irrigation, it is extremely difficult to establish vegetation in arid and semiarid climates.

Soil covers not only serve as growth media but as barriers to block or reduce radon emanation, radioactive particulates, and gamma ray emission. However, in most areas, without irrigation, survival of seedlings is poor, and the upward migration of salts may further limit survival. Further, shallow covers, defined as depths of cover less than about 60 cm (Dreesen et al. 1978, Vavilov et al. 1977), to moderately deep, at about 1 m (Macbeth et al. 1979, Dreesen et al. 1978), will not block radon gas emissions. But an earth cover of 61 cm can reduce gamma ray exposure to natural background levels; 610 cm would be required to reduce radon flux to the normal background levels (Schiager 1974). Predictive models by Clements et al. (1978) correlated well with actual measurements by Dreesen et al. (1978). These barrier soil depths depend on the soil density and moisture content (Rogers et al. 1979, Nelson et al. 1980).

Improvements to shallow soil cover.—In uranium mill tailings revegetation, the cover of topsoil and other earth materials placed over the tailings must enhance vegetation growth and provide a barrier to radiological emissions above background levels. The requirement for a 3 m minimum thickness cover of earth material is not considered by mining industry as a totally satisfactory solution based on economics and the availability of cover material (U.S. Nuclear Regulatory Commission 1980b). Thus studies have continued on shallow soil covers in seeking economical, effective methods to stabilize tailings piles and to isolate radioactive elements from the biosphere.

Several techniques should be considered to augment shallow soil covers. Some of these techniques are particularly useful in providing quick temporary stabilization.

1. Place a layer of coarse textured overburden material over the tailings surface to break capillary attraction of tailings fluid (Macbeth et al. 1979).
2. Place a layer of clay cap, with high exchange capacity, over the tailings surface to absorb contaminants and also to provide a physical barrier to upward migrations of ions (Macbeth et al. 1979, Gee et al. 1980). Moisture in the soil cover is very important. With materials, such as clays, which have been wetted, radon can be attenuated to the prescribed flux limit with relatively thin layers of cap material (U.S. Nuclear Regulatory Commission 1980a).
3. Place a layer of riprap cover mixed with soil over the tailings to conserve soil moisture, trap eolian particles, trap precipitation, protect seedlings from wind damage, and inhibit soil erosion (Dreesen et al. 1978).
4. Establish water harvesting structures to collect rainfall, thereby increasing available soil moisture (Packer and Aldon 1978).
5. Cover the raw tailings with plastic membranes (Macbeth et al. 1979).
6. Apply an asphalt emulsion on tailing surface (Hartley et al. 1979, Havens and Dean 1969).

7. Riprap cover to suit the situation.
8. Fertilize or treat with lime to improve plant growth.
9. Install snow fencing to increase water accumulation and retention.
10. Fence the area to exclude grazing animals.
11. Use cobbles (large stones) as biobarriers to exclude plant roots and ants and other burrowing animals, to prevent them from translocating contaminated materials to the surface (Cline et al. 1980). A 3-m earth cover may not be a barrier to some species of harvester ants (e.g. *Pogonomyres occidentalis*) which bore that deep (Headlee and Dean 1980).
12. Use resinous adhesives, lignosulfonates, elastomeric polymers, milk of lime, mixtures of wax, tar and pitch, potassium and sodium silicates, or neoprene emulsions to form crust on top of tailings surfaces (Havens and Dean 1969, Dean and Havens 1971).
13. Use root toxins together with cobbles to inhibit downward root extension (Cline 1979).

Shallow Soil Cover With Irrigation

Some problems associated with irrigation (e.g. the upward movement of contaminants as production of vegetation increases) may be offset to some degree by the deep leaching of ions below the rooting zone with irrigations. Also, survival of vegetation after irrigation is stopped may be a problem. Procedures to improve shallow soil cover without irrigation can be applied to avoid this problem.

Deep Soil and Overburden Cover

Information currently available indicates that deep cover over radionuclides is the most acceptable treatment (Dreesen et al. 1978; U.S. Nuclear Regulatory Commission 1979a, 1980a; Macbeth et al. 1979) as well as the one required by law.

The primary restraint to deep cover is the cost of the covering operation, which includes excavating, hauling, backfilling, and compacting. The cost rises if suitable material is not available on site, and varies by the volume and area of the tailings area and the strength of the radioactivity. Thus, one of the goals of research is to determine the depth of cover needed to suppress radon emission to a desired level. The advantages of deep soil cover include: (1) greater reduction of radon gas emissions, (2) reduction in need for long-term monitoring, (3) more and easier treatment options between the tailings surface and ground surface, and (4) increase in soil moisture storage capacity.

Natural invasion of surrounding plant species would be slow in the beginning, but individual plants will last longer once a plant community is established. However, some deep rooted plants, such as Russian thistle, may invade the plot. Generally, if the cover is deep enough to prevent plant roots and moisture from pene-

trating into the tailings, little contaminant uptake should result. Even so, the problem of upward migration of contaminants remains because the upward travel distance of salts over time has not been established. This is a continuous process as suggested by salt distribution with depth and the constant regeneration of salts (Markos 1979). Further, radium-226 transport by vegetation to the surface increases sharply with time (Vavilov et al. 1977), because soil and plant aging significantly increases the ion uptake (Cline and Uresk 1977). Thus, a deep soil cover may not inhibit the upward movement of contaminants over time.

Improvements to deep soil and overburden cover.—If water is available for irrigation, plant establishment improves. Therefore, techniques that limit deep percolation should be devised. Other techniques discussed under improvements to shallow cover should be considered also.

Riprap Cover

The long-term sustenance of vegetation cover is questioned by many workers (Dreesen et al. 1978). They recommend the use of riprap as a final treatment. Riprap, in addition to providing protection against erosion, collects eolian soil particles and thus provides a more favorable plant habitat for vegetation to grow between rocks.

Plant Selection

The approaches used to obtain ecologically adapted plants for reclamation of uranium-mined lands, with some exceptions, are similar to those for coal-mine lands. First, any species used must be able to withstand arid or semiarid conditions found at the uranium or coal basins. Second, selected species must be adapted to the edaphic factors of low or high pH, nutrient deficiencies, and chemical imbalances. Species selected for uranium spoil or tailings also must be able to withstand the effects of radioactivity and trace elements, and still limit their uptake of these elements. It is also desirable for plants to have root systems which limit the upward emanation of radon through the soil. Third, the plants must fit the reclamation objectives of cover, productivity, habitat for birds or animals, esthetic values, etc. The task of plant selection, perhaps the most important in revegetation research, is difficult because the chemical and radiological properties differ among sites, and ion uptake varies among species (Dreesen et al. 1978).

The most simple and effective selection method seems to be the use of species that have invaded the spoil and tailings pile. Dreesen et al. (1978) noted three plant species (*Atriplex canescens*, *Kochia scoparia*, and *Sitanion hystrix*) that successfully invaded tailings piles at Grants, N. Mex. Reynolds et al. (1978), Kelley (1979), and others (Thames 1977) also investigated various plant species which should be considered for tailings revegetation in the Southwest. Plant species

that have commonly invaded uranium overburden piles in Wyoming were noted by May (1973). However, the concentration ratios (e.g. of U, V, Ra, Se, Mo, As, Co, etc.) for many of these plants have not been determined as yet.

According to geobotanists (Cannon 1962, Froelich and Kleinhampl 1962, Kleinhampl and Koteff 1962, Kleinhampl 1962), the distribution of plants in the environment of the uranium deposit is controlled by the presence of selenium, sulfur, and other associated trace elements. On the flat beds, at lower altitudes, of the Colorado Plateau, there is a correlation between major plant zones and stratigraphic units (Cannon 1962). Kuchler (1964) also described potential natural communities. Knowledge of the mechanisms for natural formation of plant associations in these mineralized regions may provide clues to plant species selection for these areas. The experiences of Ludeke (1977), Nielson et al. (1972, 1973, 1978), and Peterson and Nielson (1973) in mill tailings revegetation provide useful information for plant selection in mine tailings ponds. Selection of plants unpalatable to animals, which fit the criteria of adaptability and low uptake of contaminants, also should be considered.

Field experiments in selecting and establishing plant species are best conducted at inactive sites (Dreesen et al. 1978, Nielson and Peterson 1978). On active ponds, slurries are constantly transported and flooding occurs at regular intervals; therefore, these ponds generally are not practical for planting experiments. Greenhouse, pot lysimeter, and growth chamber experiments are necessary and should be integrated, for example, in (1) expediting plant selection experiments, (2) testing theories of contaminant uptake or leaching for testing under field conditions, (3) providing uncontaminated "control" measurements, and (4) conducting bioassays.

Shaping and Sloping

One of the most important factors influencing the containment capability of tailings piles is the degree to which ground, surface water, and wind contact the tailings material and subsequently transport the radionuclides, radon gas, and trace elements. Shaping and sloping both the tailings and the cover strengthens the stability of the waste pile by controlling the intake and loss of water from the pile and ensures a degree of permanence that vegetation sometimes cannot provide. This also improves the establishment of vegetation.

Riprap treatment has been very effective in reducing wind and water erosion and trapping eolian soil particles, which form a microhabitat for the vegetation. Therefore, this treatment and its modification should be considered in site preparation studies.

Several typical questions have to be answered: Will the depressions of the tailings surface be retained? If so, how will the water level be controlled? If not, how will the depression be filled and will the final surface be flat or contoured to a slightly domed shape? If contoured, what slope angles are favorable? Will the em-

bankment side slopes be flattened? Are there outside sources of surface runoff into the pile? Are there internal sources of recharge through hydrogeologic connections? How is the concept of riprap treatment with sloping and shaping best utilized? What kinds and combinations of vegetation, grasses, shrubs, or trees will promote the stabilization of embankment slopes? What is the effect of vegetation on the ground water found in inactive piles and its recharge?

The answers depend on the actual conditions at the site, but all decisions should be aimed at the objectives of reducing wind and water erosion, and maximizing the stability of the embankment.

HEALTH CONSIDERATIONS

In 1970, it was accepted that waste tailings with less than 0.05% uranium content were potentially harmful and should not be used for construction material (U.S. Environmental Protection Agency 1977). Moreover, before 1976, mill operators were not required to monitor radon levels (U.S. Nuclear Regulatory Commission 1979a). On November 8, 1978, Public Law 95-604 was enacted authorizing public funds to reclaim exposed, abandoned tailings. Thus the recognition and evaluation of possible radiological health hazards associated with ore and waste products (Ford, Bacon and Davis Utah Inc. 1976, 1977a-r inclusive; Haywood et al. 1979, 1980a-c) is really not too far from its beginning.

Pathways of Radiation

Three pathways can result in radiation exposure to humans, according to present views.

1. Whole body gamma irradiation directly from the pile itself or from the deposition of windborne material.
2. Deposition of radionuclides in the body or in an organ of the body because of direct ingestion of mill tailings material or of water or food that has been contaminated by the tailings material.
3. Deposition of radionuclides in the body or in an organ because of inhalation, primarily of alpha irradiation into the pulmonary region. Deposition in other areas of the body can also occur as material circulates from the pulmonary region through the bloodstream.

The consensus of literature is that the radiation dose to the pulmonary region is the most critical pathway (U.S. Environmental Protection Agency 1977, U.S. Nuclear Regulatory Commission 1980a, 1980c). Exposure may be limited or prevented by controlling and stabilizing the tailings piles. The goal is to reduce radiation emanation to as near background levels as possible. A wet or moist tailings pile or overburden prevents wind pick-up of particulates (believed to be nuclides of thorium-230, radium-226, polonium-210, and lead-210).

The radon-222 itself produces only about 5% of the radiation dose (alpha energy) that contributes to the biological hazard. The main hazard comes from the radon daughters. These daughter products of radon and thorium are electrically charged when formed and tend to attach themselves to the dust particles normally present in the atmosphere (U.S. Environmental Protection Agency 1977). Thus, they become the only significant natural radionuclides leading to widespread exposure through inhalation. Because more than one nuclide is involved, a total energy unit was developed. This unit, the working level (WL), was also designed to be a safe occupational level of exposure for miners. When this standard was first developed, a uranium miner could work in an atmosphere containing one WL. This safe level has now been reduced to one-third WL.

One WL is defined as any mixture of short half-life radon daughters in a liter of air which will ultimately produce 1.3×10^5 MeV (million electron volts) of alpha energy. Also, 100 pCi of radon-222 per liter of air, in equilibrium with its short half-life daughters, will produce 1.3×10^5 MeV of alpha energy or 1 WL of exposure. Further, a miner who worked 8 hours per day, 5 days per week, for 1 month (based on 173 hours of exposure), in a 1-WL atmosphere, would receive one working level-month (WLM) exposure. Thus, this same exposure for 1 year would be 12 WLM, which was originally considered a safe yearly occupational exposure. A person working on the surface of a tailings pile with natural surface ventilation probably would be exposed to considerably less, for example, than 1 WLM of exposure. According to Schiager (1974) average, annual, outdoor, radon progeny concentrations exceeding 0.003 WL in addition to background are very unlikely because of dispersion in the atmosphere and the lack of time available for development of radon daughters.

The WL of each tailings pile or mine spoil dump should be evaluated. A variety of health physics equipment—respirators, geiger-mueller and scintillation probes, dosimeters, etc.—are available to monitor and limit the worker exposure and contamination.

In August 1970, the Public Health Service provided guidance to the State of Colorado (10 CFR 712) concerning gamma radiation and radon daughter exposures. The guidance provided for an upper level, above which remedial action was suggested; an intermediate level where corrective action was based on further evaluation of the specific location; and a lower level below which no action was believed necessary. The working level guidance values were 0.05 WL and 0.01 WL above background, and the gamma radiation values were 0.1 MR per hour and 0.05 MR per hour above background, upper and lower guides, respectively. At the active tailings pond, at the Jackpile Mine, Laguna, N. Mex., the gamma value recorded on the geiger counter was 0.4 mR per hour (uncorrected for background). At an inactive tailings pile (San Mateo Mine Site, Mt. Taylor Ranger District), an average gamma value of 0.2 mR per hour (uncorrected) was recorded. These values indicate that these materials pose a clear health risk and must be handled with care.

Summary of available estimated radiation dose rates in the U.S. from all sources (U.S. Environmental Protection Agency 1977) indicates that, next to ore mining and milling (at 100,000 mrem per year), the largest doses of 140 to 14,000 mrem per year taken through the pulmonary area can be derived from inactive uranium mill tailings piles. In contrast, the average individual dose from medical and dental x-rays is 103 mrem per year.

According to the USDA Radiological Safety Handbook (Kwast and Roberts 1975), background radiation should be maintained at an acceptable level in a radiological environment, and persons younger than 18 years old and, whenever practical, women of child-bearing age, should not be assigned to work with radiation. Maximum permissible exposure to radiation workers in restricted areas are specified in 10 CFR 20, as follows:

	Rems per calendar quarter	Millirems per 40-hour week
A. Whole body; head and trunk active blood-forming organs; lens of eyes or gonads	1.25	100
B. Hands and forearms; feet and ankles	18.75	1,442
C. Skin of whole body	7.50	577

Unless specific exceptions are approved by the USDA Radiological Safety Committee, the maximum permissible whole body exposure limit for USDA radiation workers shall not exceed 25 millirems per 40-hour week (Kwast and Roberts 1975). Recent standards developed by the U.S. Environmental Protection Agency (40 CFR 190) limit annual dose commitments to offsite individuals to 25 mrem per year or less (doses to whole body or single organ, excluding doses from radon and its daughter products). As of March 1975, the U.S. Environmental Protection Agency has adopted the policy (41 FR 28409) of assuming a linear relationship between population exposures to ionizing radiation and its biological effect. In summary, it says that there is some potential ill health attributable to any exposure to ionizing radiation and that the magnitude of potential ill health is directly proportional to the magnitude of the dose received. Thus, the linear hypothesis (all radiation is potentially harmful) by itself precludes the development of acceptable levels of risk based solely on health considerations (U.S. Environmental Protection Agency 1977).⁵

Some degree of exposure to radioactivity above normal background radiation may be inevitable to persons within uranium waste disposal areas. Because there

⁵The Rocky Mountain Forest and Range Experiment Station takes no position on health and radiological effects of exposures to uranium mill tailings.

are no official guidelines on exposure limits for uranium reclamation workers, these limits may have to be developed by U.S. Nuclear Regulatory Commission or U.S. Environmental Protection Agency.⁶ Radiological research by agencies of the U.S. Department of Agriculture requires, at its outset, a review of the research program by the Radiological Safety Staff, Science and Education Department, U.S. Department of Agriculture. Approval to proceed with uranium mill tailings revegetation research programs is granted only if the proposed program adequately addresses the following safety criteria:⁷ (1) radiation surveys and sampling to be conducted, (2) training and experience of employees relative to radiological and toxic hazards of exposure to uranium and its daughters, (3) the plan to keep exposures to uranium and its daughters to a minimum, (4) personal hygiene requirements of employees (protective clothing, respirators, and eating, drinking, and smoking only in designated areas), (5) proper methods of decontamination, (6) bioassay procedures to be used, and (7) the design and operation of any ventilation systems.

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- ⁶According to David R. Dreesen (written communication), dose models developed by Argonne National Laboratory (U.S. Nuclear Regulatory Commission 1979b, 1980c) will aid in the assessment of health hazard to revegetation workers. U.S. Environmental Protection Agency (Office of Radiation Programs, Las Vegas Facility) also has expertise in this area.
- ⁷Written communication from Robert D. Jarrett, Radiological Safety Officer, Beltsville, Maryland, (August 26, 1980) on file at the Rocky Mountain Forest and Range Experiment Station's Research Work Unit at Rapid City, S. Dak.
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Yamamoto, Teruo. 1982. A review of uranium spoil and mill tailings revegetation in the western United States. USDA Forest Service General Technical Report RM-92, 20 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

The following aspects of uranium mine and mill tailings management are reviewed and discussed: (1) the history of the uranium remedial action program, (2) magnitude of the uranium spoils problem, (3) uranium deposits, mining, and milling, (4) status of reclamation, (5) problems in revegetation of uranium spoils and tailings, and (6) health and safety conditions.

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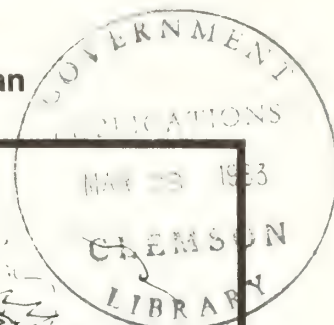
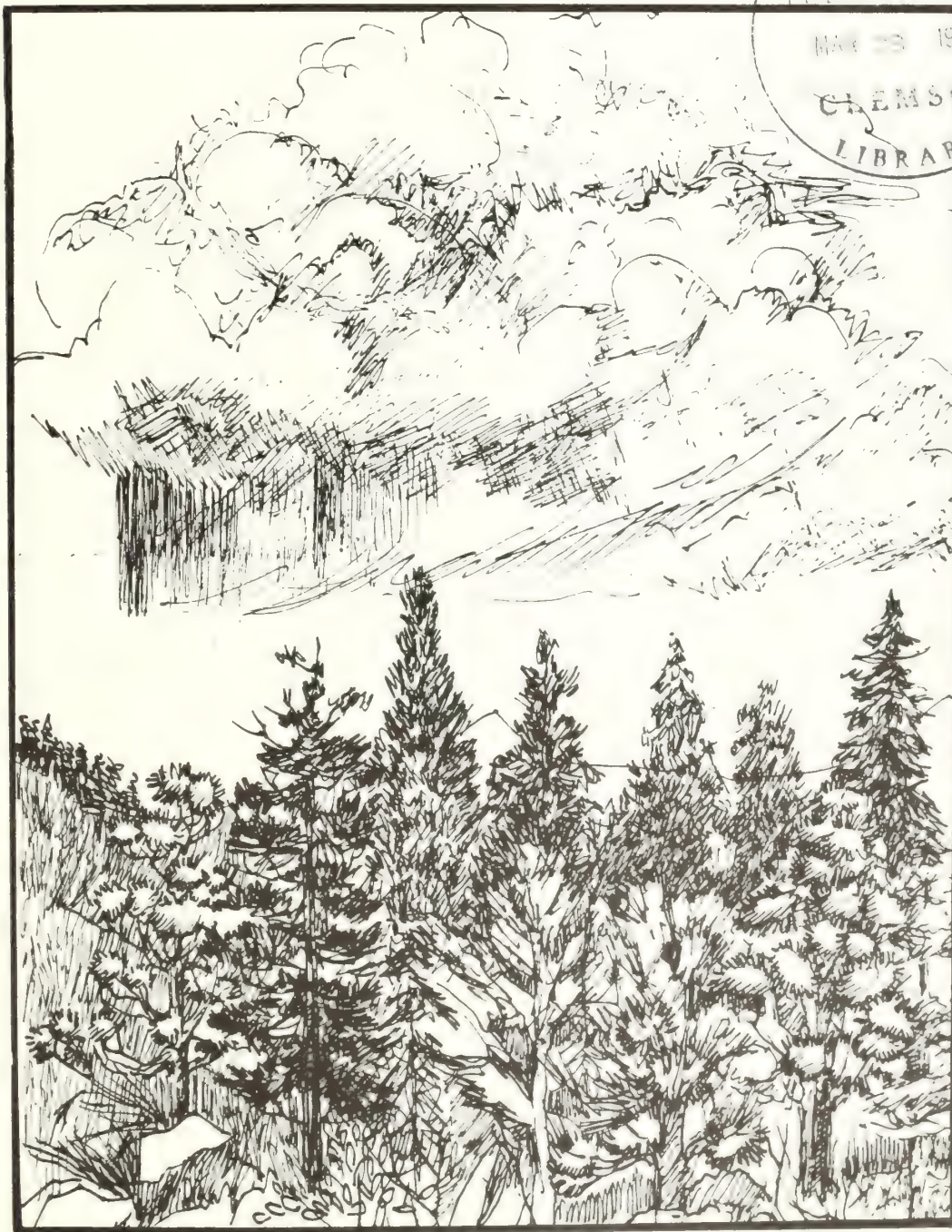
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Precipitation and Temperature Characteristics of Forested Watersheds in Central Arizona

Ralph E. Campbell and Michael G. Ryan



General Technical Report RM-93
Rocky Mountain Forest and
Range Experiment Station
Forest Service
U.S. Department of Agriculture

Precipitation and Temperature Characteristics of Forested Watersheds in Central Arizona

**Ralph E. Campbell, Research Soil Scientist
and
Michael G. Ryan, Statistician
Rocky Mountain Forest and Range Experiment Station¹**

Abstract

Precipitation and temperature characteristics of the Utah and alligator juniper woodlands and ponderosa pine forest types, on the Beaver Creek experimental watersheds, are described using 23 years of record. Mean annual precipitation ranges from 17.6 inches in the Utah juniper type at 5,000 feet elevation to 25.0 inches in the ponderosa pine type at 7,400 feet elevation. Average precipitation is greater for winter storms than for summer storms. Precipitation intensity exceeding 3 inches per hour for 30 minutes' duration may be expected to occur on the average at 25-year intervals on all three vegetation types. Temperatures are closely correlated with elevation. The climatic patterns, both precipitation and temperature, are quite representative of similar vegetation types and fit into a continuum within Arizona and New Mexico.

¹Headquarters is in Fort Collins, in cooperation with Colorado State University. Research reported here was conducted at the Station's Research Work Unit at Flagstaff, in cooperation with Northern Arizona University.

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INTRODUCTION

Ponderosa pine (*Pinus ponderosa* Laws.) forests and the Utah juniper (*Juniperus osteosperma* Little) and alligator juniper (*J. deppeana* Steud.) woodlands in north-central Arizona have been intensively studied by the USDA Forest Service as part of the Beaver Creek watershed network (Brown 1965, 1970, 1971; Brown et al. 1970, 1974; Clary et al. 1974; Williams and Anderson 1967). Climatic data such as precipitation, temperature, and humidity have been collected for more than 20 years, primarily to determine the influence of local climate on water runoff from forested watersheds. In addition, long-term climatic data are important to managers for reasons such as estimating biomass production and sediment yield, and for road planning. This paper characterizes the precipitation and temperature regimes of the three vegetation types within the Beaver Creek watersheds, compares these regimes with other areas of the Southwest, and projects probabilities of future storm intensities.

The hypothesis tested is that precipitation regimes on the Beaver Creek watersheds represent substantial areas of similar vegetation types in Arizona and New Mexico. Further, the temperature regime on the Beaver Creek watersheds is within a continuum of the greater temperature regime in Arizona.

SITE DESCRIPTION

The Beaver Creek experimental watersheds, which drain into the Verde River, are in the Mogollon Plateau region of Arizona, about 25 to 35 miles south of Flagstaff (fig. 1). Bedrock under the watershed is basalt with some minor faulting (Beus et al. 1966, Scholtz 1968). The watersheds are characterized by breaks, steep canyons, and valleys. Average elevations of the Utah juniper watersheds range from 5,200 to 5,500 feet, the alligator juniper watersheds range from 6,200 to 6,400 feet, and those in ponderosa pine range from 6,400 to 8,000 feet. The Beaver Creek watershed as a whole slopes about 3% to the southwest.

The predominant soil of the juniper watersheds is a Udic Chromustert, Springerville series (surface texture-clay), developed in material weathered from basalt. Predominant soils of the pine watersheds are Eutroboralfs and Argiborolls of Brollier (loam to fine clay), Siesta (silt loam), and Sponseller series (stony silt

loam), and are developed on basalt and cinders (Williams and Anderson 1967).

The position of the Mogollon Rim in relation to the central valleys and the desert to the southwest strongly influences the temperature regime and precipitation patterns. According to the Koppen classification scheme discussed by Trewartha (1968), the area is classified as temperate, continental: mean monthly temperature is above 50° F during 4 to 7 months of the year, and precipitation occurs every season of the year, with rain in summer and snow in winter. Moisture for the moderately heavy precipitation of July and August comes almost entirely from the Gulf of Mexico. However, most of the high-record summer rains are associated with deep surges of tropical air from the Gulf of California and the Pacific Ocean. Most winter precipitation is the result of frontal storms moving east or northeast from the Pacific Ocean. Late spring (May-June) and early fall (September-November) are generally dry periods (Sellers and Hill 1974).

METHODS

Instrumentation

Precipitation, temperature, and humidity gages were installed to monitor watershed climate beginning in 1957. Gages were added to the climatic monitoring network when the study area was expanded in 1962, 1965, 1972, and 1976. After watershed evaluation studies were completed, some gages were removed from the network in 1965, 1973, and 1976. The network now consists of 44 gages (fig. 2). Length of record of existing gages ranges from 4 to 23 years.

Recording gages for precipitation are of the weighing type and produce ink trace records on 24-hour charts. Standard (nonrecording) gages are read by weighing every 2 weeks; they are charged with mineral oil to prevent evaporation, and additionally with ethylene glycol during winter to prevent freezing. The 8-inch-diameter rims are 2 m above ground.

Hygrothermographs in weather instrument shelters are used to continuously record both temperature and humidity at seven locations. Humidity gages are calibrated periodically using an Assman psychrometer as a standard. The temperature gages are calibrated with maximum, minimum, and standard thermometers. Five weather stations are on pine watersheds, and one each is on Utah juniper and alligator juniper watersheds.

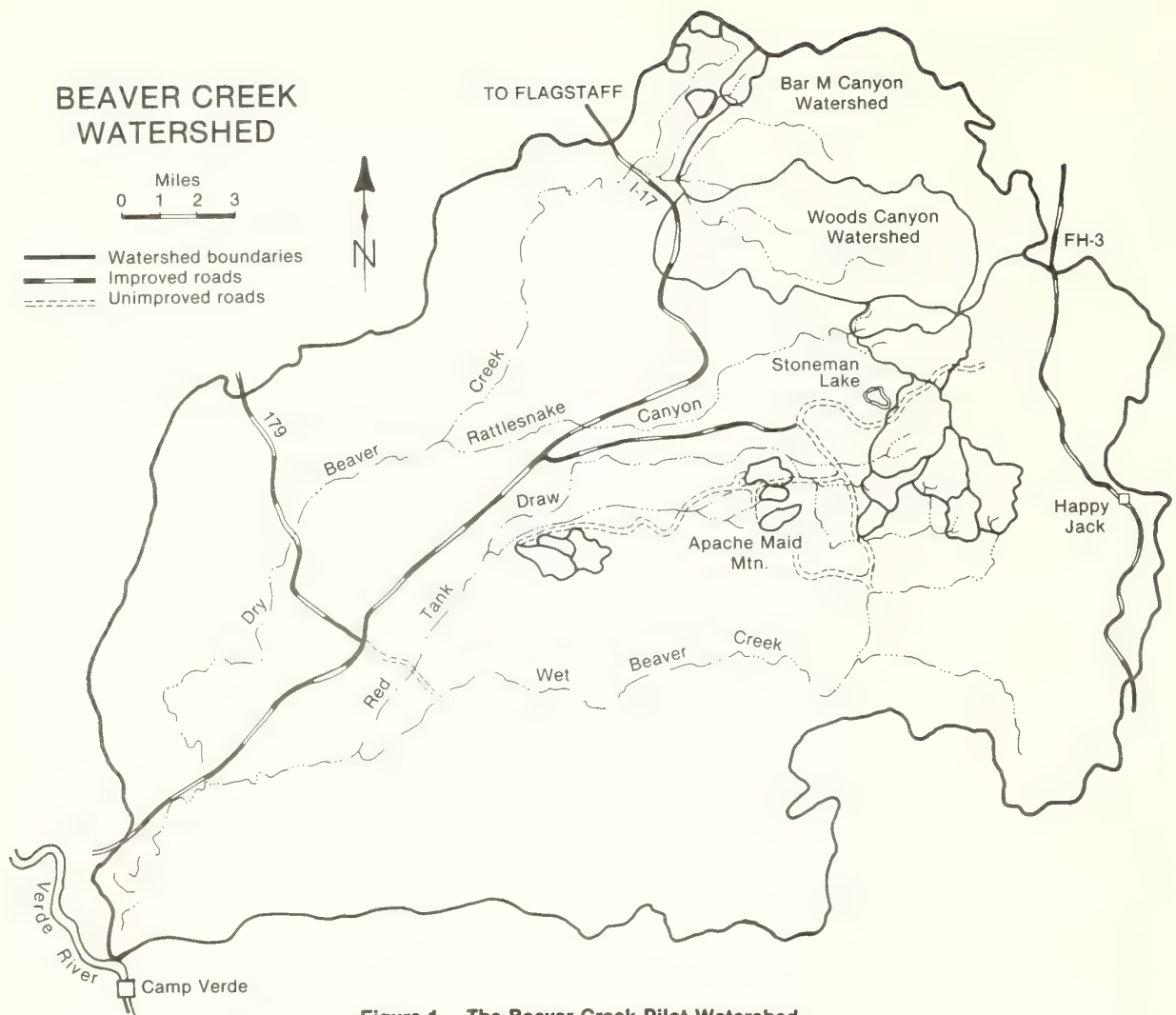


Figure 1.—The Beaver Creek Pilot Watershed.

Climatic Data Processing

Climatic records are kept on a water year basis which begins on October 1 of the previous calendar year. Winter season is defined as the months October through April; summer, May through September.

Precipitation data gathered from recording and standard gages are processed through a group of computer programs each water year. The following information is generated by these programs:

- amount and type of precipitation (rain, snow, or mixed).
- duration (in hours) of storms at each gage.
- maximum n-minute rain intensities per storm for six values of n (5, 15, 30, 60, 120, 360) at each gage. Storm intensities are calculated only for rain events with precipitation greater than 0.25 inches.
- amount and duration of storms by watershed.
- summaries of precipitation by day, month, season, and year for each gage and watershed.

Information from the 24-hour precipitation charts is used to calculate the storm intensity and duration data.

Volume data from the standard gages represent the absolute precipitation amount. Average precipitation on a watershed is found by combining the records of gages representing portions of the watershed according to Thiessen formulas (Thiessen 1911). Daily maximum and minimum temperature and humidity values are read from the continuous trace charts and are stored in computer data files. Climatic data are available for reference from Rocky Mountain Forest and Range Experiment Station, Flagstaff.

DATA ANALYSIS

Records from one precipitation gage each in the Utah and alligator juniper types were used in calculating the long-term annual precipitation averages, while records from seven gages, each within a different experimental watershed, were used for ponderosa pine. Each of the gages selected represents 23 continuous years of record. The gage in the Utah juniper represented a 1,000-acre watershed area ranging in elevation from 5,000 to 5,400 feet, the gage in the alligator juniper

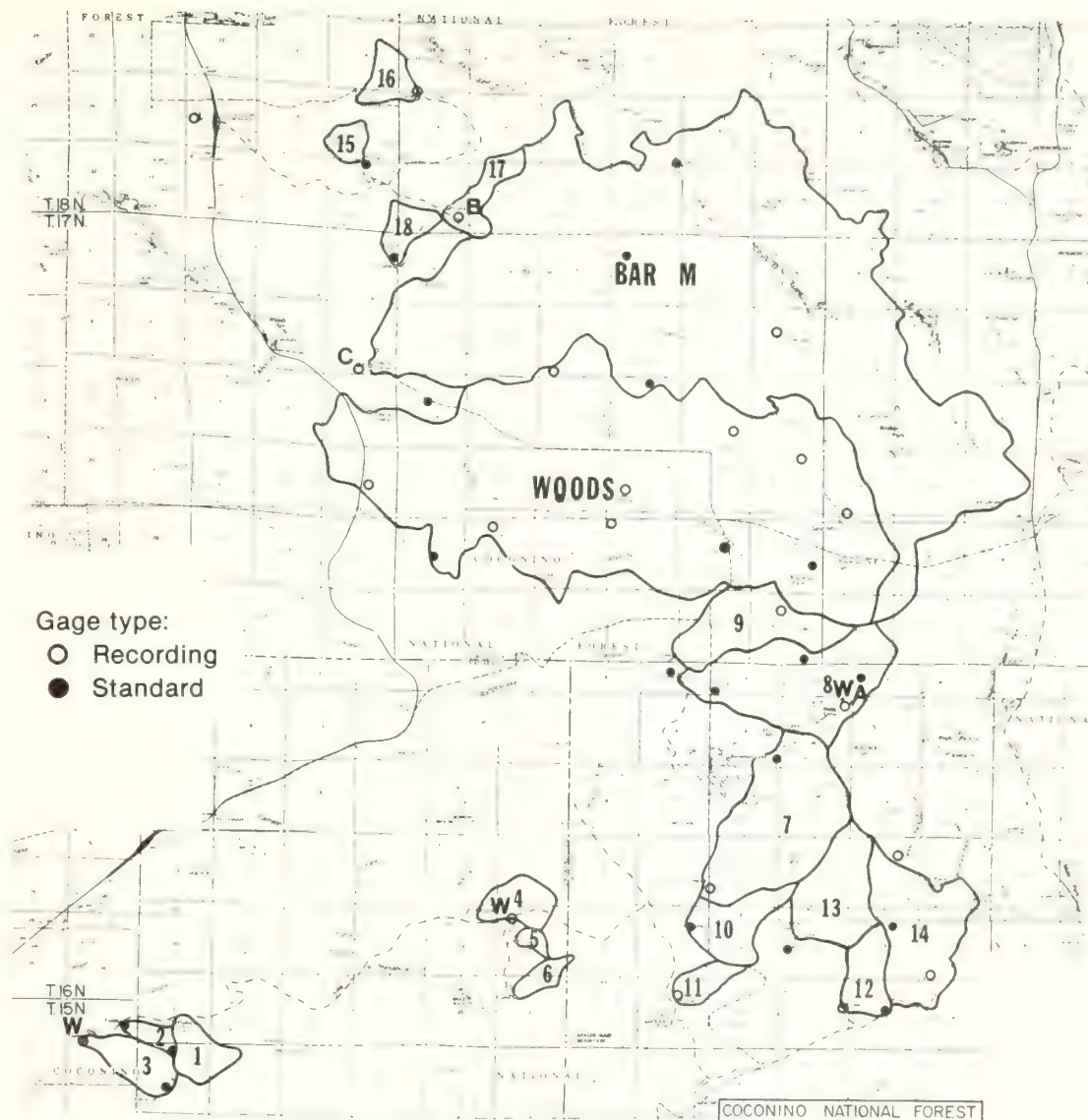


Figure 2.—Location of precipitation gages and weather stations on the Beaver Creek watershed, Arizona. (W = weather station; A, B, and C = gages used in correlation analysis.)

represented a 600-acre watershed area with an elevational range of 6,300 to 6,400 feet. The seven pine gages represent about 6,000 acres of watershed area ranging in elevation from 6,400 to 7,500 feet.

Some stations are operational in the summer only, and the long-term monthly precipitation averages for the pine were calculated using three gages in addition to the seven used for the annual precipitation. These three gages had a continuous record in the months they represented for the entire 23-year period. When more than one gage was used to represent a vegetation type in a given month and year, volumes of these gages were averaged. The reported standard errors indicate the variation of these averaged volumes.

An estimate of the spatial variation among precipitation gages in the pine type was found by calculating seasonal and annual averages for 28 to 30 gages for five separate years. These years represent low, medium, and high amounts of annual precipitation. Variability of precipitation among gages was uniformly

low; coefficients of variation ranged from 8% to 19% and were generally about 12%.

One station in each of the three vegetation types was used to characterize the temperature, humidity, and storm regimes (fig. 2). Station 1 and 9 represent the Utah juniper and alligator juniper types respectively. They are the only stations in these types at which temperature and humidity records are kept. Station 20 was chosen to represent the pine type because it has the longest continuous record of temperature and humidity in the pine watersheds. The elevations of these gages are: Utah juniper—5,000 feet, alligator juniper—6,240 feet, and ponderosa pine—7,400 feet. Records from the years 1958-1980 were used to calculate long-term averages of temperature and storm parameters.

One of the desired applications of historical precipitation data is to predict the probable frequency of rainfall intensity for future events. Summer rainfall data were used to predict the expected frequency (recur-

rence interval) of maximum intensities for durations ranging from 5 to 360 minutes.

First, the annual maximum intensities for each time interval (5, 15, 30, 60, 120 and 360 minutes) for the 23 years of record were listed in descending order.

Second, recurrence intervals (T) were paired with these ranked intensities (Chow 1964) where $T = (n + 1)/m$; n = the number of years of record (here 23), and m = order number of the intensities. This produced a series ranging from 24 to 1.043.

Next, the T values were transformed to K values in order to establish a linear relationship between intensity and recurrence interval (Chow 1953):

$$K = (-\sqrt{6}/\pi) \{ \gamma + \ln \ln [T/(T - 1)] \}$$

where γ , a Euler's constant = 0.57721.

Linear regression coefficients were then derived for each time duration and each of three precipitation stations. The differences of regression slopes among vegetation types were tested for each time interval using covariance analysis.

Only summer storms were considered in the analysis. High intensity summer rainfall has direct bearing on flood events, whereas winter storms rarely exceed intensities of 1 inch per hour.

The relationship between precipitation and elevation was analyzed using linear regression. Eleven-year annual and seasonal averages of 16 gages ranging in elevation from 5,000 to 7,600 feet were used for the analysis. To include more gages, the 11-year period (1963 to 1973) instead of the 23-year period (1958 to 1980) was chosen.

Beaver Creek climate in relation to Arizona as a whole was examined in terms of average annual pre-

cipitation with respect to elevation at 77 stations. Data were from National Climatic Center (1980).

Variability among temperature stations in the pine type was estimated by averaging the monthly maximum and minimum temperatures of five stations for two separate years. The coefficients of variation are generally low (about 7%) and range from 3% to 20%. Maximum temperatures ($CV \cong 5\%$) were less variable than the minimum temperatures ($CV \cong 10\%$). There is no estimate of the spatial variability of temperature on the juniper watersheds.

RESULTS AND DISCUSSION

Precipitation

Annual and Seasonal Precipitation

Mean annual precipitation is 17.4 inches in Utah juniper, 21.8 inches in alligator juniper, and 25.0 inches in ponderosa pine (table 1). Annual precipitation extremes in the period of record were 7.6 and 26.0 inches in Utah juniper, 12.6 and 34.1 inches in alligator juniper, and 15.2 and 39.4 inches in ponderosa pine. These record lows and highs were set in two consecutive years; the wettest year was 1973, followed by the driest year in 1974.

Annual precipitation for the three vegetation types on the Beaver Creek watersheds is similar to other sites in Arizona with comparable orographic relationships. New Mexico sites are somewhat similar; however, they differ slightly in that the winters are dryer. A higher proportion of precipitation occurs in July and August in New Mexico than in Arizona. Since precipi-

Table 1.—Annual precipitation (inches) on Utah and alligator juniper woodland and ponderosa pine forests, Beaver Creek watersheds, Arizona

Year	Utah juniper			Alligator juniper			Pine		
	Winter	Summer	Total	Winter	Summer	Total	Winter	Summer	Total
1958	12.28	8.73	21.01	16.56	10.35	26.91	13.76	11.93	25.69
1959	6.12	6.33	12.45	6.73	6.45	13.18	8.69	8.31	16.99
1960	11.81	5.91	17.72	15.25	7.36	22.61	18.33	6.29	24.62
1961	8.49	8.85	17.34	10.57	10.54	21.11	12.67	11.40	24.07
1962	9.97	4.63	14.60	13.13	5.38	18.51	17.42	6.03	23.45
1963	6.44	6.16	12.60	8.50	7.23	15.73	10.82	8.49	19.29
1964	8.70	9.33	18.03	10.23	6.42	16.65	13.69	7.37	21.06
1965	15.97	7.01	22.98	19.19	8.56	27.75	22.98	10.19	33.17
1966	13.09	5.38	18.47	16.81	7.58	24.39	18.87	7.92	26.79
1967	7.47	9.68	17.15	10.40	7.69	18.09	12.48	12.31	24.79
1968	11.16	3.55	14.71	13.33	6.87	20.20	17.08	6.81	23.90
1969	11.67	6.95	18.62	15.94	6.58	22.52	19.31	6.43	25.73
1970	9.57	8.08	17.65	11.84	10.33	22.17	12.56	11.05	23.61
1971	5.55	7.71	13.26	6.99	9.45	16.44	8.75	10.70	19.45
1972	6.20	6.16	12.36	8.46	8.44	16.90	10.13	9.19	19.32
1973	23.83	2.20	26.03	30.38	3.76	34.14	35.68	3.70	39.38
1974	5.59	1.97	7.56	7.95	4.62	12.57	9.95	5.19	15.15
1975	11.07	3.28	14.35	13.91	4.84	18.75	16.72	5.32	22.04
1976	10.17	8.00	18.17	13.61	7.66	21.27	16.28	9.65	25.93
1977	6.42	7.43	13.85	7.26	12.85	20.11	8.93	11.45	20.38
1978	18.54	2.56	21.10	23.35	3.76	27.11	24.92	4.43	29.35
1979	19.80	4.18	23.98	25.30	5.02	30.32	28.06	6.12	34.18
1980	20.33	4.96	25.29	27.17	6.56	33.73	29.92	5.50	35.43
Mean	11.31	6.05	17.36	14.47	7.32	21.79	16.87	8.08	24.95
SE	1.08	.48	.96	1.40	.48	1.24	1.52	.55	1.26

tation increases as air masses rise and cool, and winds are predominantly southwesterly, in Arizona precipitation increases on southwestern slopes with increased elevation. Areas of equivalent elevation further east which receive less precipitation reflect the rain shadow effect.

The phenomenon of increasing precipitation with increasing elevation is typically exemplified in the annual precipitation on the Beaver Creek watersheds. The principle is also evident at Santa Rita, Sierra Ancha, and McNary, as well as several other locations in Arizona.

For equivalent elevations, precipitation is slightly less at Flagstaff and Fort Valley because they are further east and north of the elevation rise. Stations still further east and at slightly lower elevations receive considerably less precipitation. Examples are Wapatki, Leupp, and Winslow. Annual precipitation on pinyon juniper woodlands ranges from 8 to 25 inches in the Southwest (Tueller and Clark 1975) and from 11.8 to 19.7 inches in Arizona (Clary and Jameson 1981). Beschta (1976) reported a range of 15 to 35 inches of annual precipitation in the Arizona ponderosa pine type with most of the areas receiving 20 to 25 inches.

The year to year variation is too great to permit detection of precipitation cycles in the 23 years of data. However, if the data are examined as 5-year moving averages some trends appear (fig. 3). The data show an indication of a 12-year cycle. The greatest mean annual precipitation was received during the period 1976-1980, while the driest period was 1959-1963.

Seasonal distribution of precipitation varies little from type to type. Winter precipitation accounts for 65%, 66%, and 68% of the annual in the Utah juniper, alligator juniper, and ponderosa pine, respectively. The standard errors are greater for winter precipitation than for summer in all three vegetation types. However, variation in precipitation between-years (reflected in the standard errors) increased with eleva-

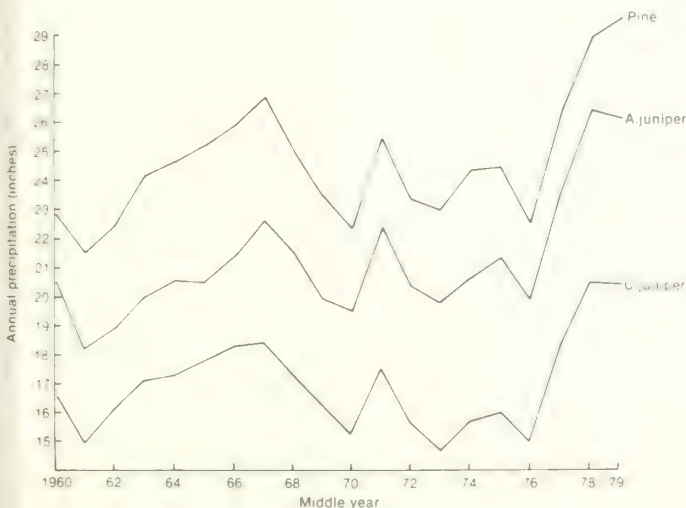


Figure 3.—Five-year moving average annual precipitation, Beaver Creek watersheds (Stations 1, 9, 20).

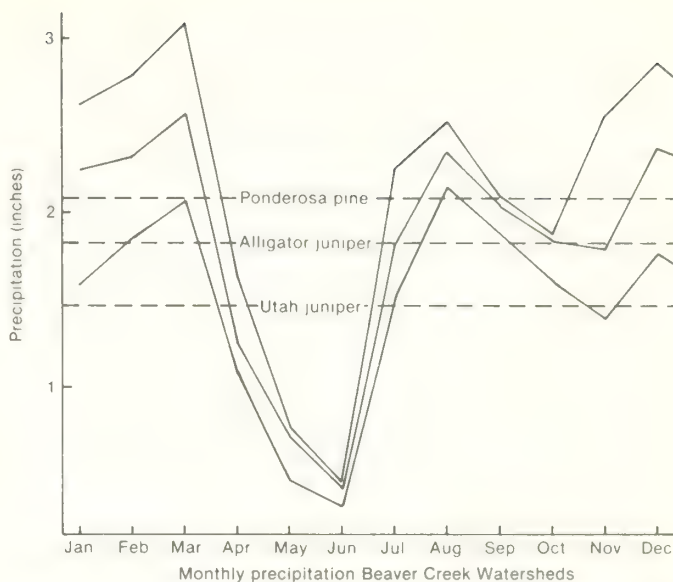


Figure 4.—Annual average of mean monthly precipitation (inches) on Utah and alligator juniper and ponderosa pine stations, Beaver Creek watersheds, Arizona 1958-1980. The horizontal dashed lines indicate averages of the twelve monthly values.

tion from Utah juniper to ponderosa pine in both winter and summer (table 1). The Utah juniper watershed receives about 30% less annual precipitation than the ponderosa pine watersheds; alligator juniper receives about 13% less. These differences increase during the winter season and subside during the summer.

Monthly Precipitation

A distinct period of low precipitation occurs on the Beaver Creek watersheds in May and June (fig. 4). June mean rainfall was 0.32, 0.42, and 0.46 inches on Utah juniper, alligator juniper, and ponderosa pine gages, respectively. Seasonal precipitation patterns also show two distinct winter peaks. For ponderosa pine and alligator juniper, the highest peak occurs in March when mean precipitation is 3.08 inches in ponderosa pine and 2.56 inches in alligator juniper. A summer monsoon peak typically occurs in August. The Utah juniper type receives more precipitation in August than in either March or December. However, the differences among watersheds were greater during the winter months than in summer. Sellers and Hill (1974) indicate that cool season precipitation is more variable from year to year than warm season precipitation. Beaver Creek data support this conclusion.

The pattern of monthly precipitation on the Beaver Creek watersheds agrees with that reported by Beschta (1976) for the ponderosa pine type in central Arizona. Pinyon-juniper sites in Colorado, Utah, and Arizona also have a similar monthly precipitation pattern (West et al. 1975). However, Springfield (1976) found that pinyon-juniper areas in eastern New Mexico receive 75% of the yearly precipitation during the growing season (April to September); Beaver Creek juniper sites receive only 40% of the yearly precipitation during the same period.

The pattern that Springfield described coincides with the pattern which generally prevails in New Mexico, with maximum precipitation in July and August, tapering off to a minimum in January. The monthly march of precipitation on the Beaver Creek watersheds follows the general pattern of the larger plateau region of Arizona (Sellers and Hill 1974) except that the proportion of precipitation received during the summer is greater in the general area than on Beaver Creek. The higher peak of winter precipitation in the ponderosa type is reflected in storage of snow. The lower summer peak coincides with lack of summer runoff from the watersheds.

Summer precipitation patterns presented by Sellers and Hill (1974) is exemplified in the Fort Valley record (not shown); more rainfall is received at Fort Valley in July than at the Beaver Creek pine stations. Since ponderosa pine responds to July precipitation in growth (Minor, personal communication)² ponderosa pine would be expected to be larger in a given age class at Fort Valley than on the Beaver Creek watersheds.

Storm Variability

To assess the variability of certain storm parameters for the ponderosa pine type, values for 20 gages were averaged for water year 1977 (tables 2 and 3). The variability for these parameters is higher than that found for average precipitation or temperature. This is likely a result of the variability of individual storms together with the partitioning of storm parameters into storm volume classes. There is no estimate of the spatial variability of storm parameters for the juniper watersheds.

Number of Storms

The total number of storms increases with elevation (table 4). Utah juniper receives 55 storms per year, alligator juniper receives 59, while 68 storms per year occur on the ponderosa pine watersheds. More than half the storms are 0.25 inch or less. Fewer than 8% of summer storms exceed 0.75 inch. In contrast, 8%, 11%, and 19% of winter storms exceed 1 inch in the Utah juniper, alligator juniper, and pine types, respectively.

²Charles O. Minor, Professor of Forestry, Northern Arizona University, Flagstaff.

Table 3.—Average storm intensity (inches/hr) of 20 gages for summer storms in the ponderosa pine type for water year 1977, Beaver Creek watersheds, Arizona

Storm class (inches)		Time interval					
		5	15	30	60	120	360
0.26-0.50	Mean	0.93	0.57	0.37	0.22	0.12	0.11
	SE	0.59	0.03	0.02	0.01	0.01	0.01
0.51-0.75	Mean	1.26	0.77	0.49	0.29	0.12	0.04
	SE	0.19	0.11	0.07	0.04	0.02	0.01
0.76-1.00	Mean	0.98	0.69	0.47	0.28	0.13	0.05
	SE	0.23	0.15	0.10	0.05	0.03	0.01
> 1.00	Mean	1.18	0.88	0.67	0.48	0.29	0.15
	SE	0.18	0.13	0.08	0.05	0.02	0.01

Storm Size

Considerably more winter precipitation occurs in the ponderosa pine type, in storms exceeding 1 inch, than in the juniper type (table 5). The amounts are 4.2 inches, 6.5 inches, and 12.6 inches in the Utah juniper, alligator juniper, and ponderosa pine. These amounts are 37%, 45%, and 62% of the winter season precipitation. The above contrasts are much less for summer storms. About 21% of summer rainfall occurs in storms over 1 inch in all three types. A high proportion of summer precipitation occurs in the < 0.25 inch size class in all three types. The average size of storm within each storm size class is the same for all classes under 1 inch (table 6), but the average amount in the > 1.0 class is greater in the pine than in the juniper type.

Storm Duration

Duration of storms by size class and by season in the three vegetation types are shown in table 7. Winter storms last approximately three times longer than summer storms in all size classes and in all three vegetation types. Storm duration within a size class is very similar among the three vegetation types. Since summer storms are considerably shorter within a storm size class, it is evident that their intensity is considerably greater.

Table 2.—Average storm duration and number of storms for 20 gages in the ponderosa pine type for water year 1977, Beaver Creek watersheds, Arizona

Storm class (inches)	Winter				Summer			
	Average duration (hr)	SE	Average number of storms	SE	Average duration (hr)	SE	Average number of storms	SE
0.02-0.25	2.58	0.11	17.4	0.4	1.85	0.08	29.3	1.0
0.26-0.50	9.97	0.80	4.3	0.3	4.06	0.29	7.4	0.6
0.51-0.75	12.30	1.52	2.2	0.2	4.01	0.72	2.2	0.3
0.76-1.00	13.04	1.63	1.1	0.2	15.39	2.54	1.5	0.3
> 1.00	27.03	0.85	3.1	0.2	12.45	0.87	1.7	0.1

Table 4.—Average number of storms per season by size class in Utah juniper and alligator juniper woodland and ponderosa pine forest, Beaver Creek watersheds, Arizona

Storm class (inches)		Utah juniper		Alligator juniper		Ponderosa pine	
		Winter	Summer	Winter	Summer	Winter	Summer
0.02-0.25	Mean	18.00	16.96	16.74	18.09	16.83	24.04
	SE	1.50	0.72	1.15	0.94	1.28	0.89
0.26-0.50	Mean	5.91	4.39	6.43	4.57	5.52	6.13
	SE	0.56	0.52	0.73	0.36	0.50	0.55
0.51-0.75	Mean	2.48	1.78	3.09	2.44	3.39	1.65
	SE	0.33	0.33	0.44	0.27	0.41	0.27
0.76-1.00	Mean	1.83	0.78	2.30	0.96	2.22	1.17
	SE	0.26	0.20	0.30	0.21	0.34	0.21
> 1.00	Mean	2.48	0.78	3.39	0.96	6.52	1.04
	SE	0.36	0.18	0.47	0.18	0.67	0.22

Table 5.—Average total precipitation (inches) per season in each storm size class. Twenty-three years of record in Utah juniper, alligator juniper, and ponderosa pine vegetation types, Beaver Creek watersheds, Arizona

Storm class (inches)		Utah juniper		Alligator juniper		Ponderosa pine	
		Winter	Summer	Winter	Summer	Winter	Summer
0.02-0.25		1.80	1.36	1.67	1.81	1.68	2.40
0.26-0.50		2.19	1.58	2.38	1.65	1.99	2.21
0.51-0.75		1.56	1.07	1.92	1.51	2.10	0.99
0.76-1.00		1.57	0.68	1.98	0.84	1.93	1.02
> 1.00		4.19	1.27	6.51	1.52	12.65	1.75

Table 6.—Average size of individual storm (inches) subdivided by storm size class and season for Utah juniper, alligator juniper and ponderosa pine types, Beaver Creek watersheds, Arizona 1958 to 1980

Storm class (inches)		Utah juniper		Alligator juniper		Ponderosa pine	
		Winter	Summer	Winter	Summer	Winter	Summer
0.02-0.25	Mean	0.10	0.08	0.10	0.10	0.10	0.10
	SE	.003	.003	.003	.003	.003	.003
0.26-0.50	Mean	.37	.36	.37	.36	.36	.36
	SE	.006	.008	.006	.007	.006	.006
0.51-0.75	Mean	.63	.60	.62	.62	.62	.60
	SE	.010	.011	.008	.010	.008	.011
0.76-1.00	Mean	.86	.87	.86	.87	.87	.87
	SE	.012	.015	.010	.016	.011	.010
> 1.00	Mean	1.69	1.63	1.92	1.58	1.94	1.68
	SE	.084	.173	.116	.165	.086	.237

Table 7.—Average storm duration (hours) by size class and season in Utah juniper and alligator juniper woodlands and ponderosa pine forest, Beaver Creek watersheds, Arizona 1958-1980

Storm class (inches)		Utah juniper		Alligator juniper		Ponderosa pine	
		Winter	Summer	Winter	Summer	Winter	Summer
0.02-0.25	Mean	2.99	1.50	2.99	1.39	3.11	1.54
	SE	0.17	0.10	1.17	0.08	0.16	0.09
0.26-0.50	Mean	8.79	3.69	9.78	4.33	9.27	4.11
	SE	0.42	0.34	0.54	0.40	0.46	0.30
0.51-0.75	Mean	15.00	4.54	14.21	5.33	14.67	8.28
	SE	0.89	0.67	0.82	0.62	0.92	1.06
0.76-1.00	Mean	19.36	8.63	20.53	5.74	17.16	8.49
	SE	1.25	1.49	1.16	1.28	1.08	1.51
> 1.00	Mean	29.54	7.35	30.16	8.68	30.58	11.17
	SE	2.16	1.34	2.01	1.59	1.28	2.06

Storm Intensity Classification

Storms can be classified or grouped based on intensities for selected n-minute durations. The number of occurrences of intensity rates of storms occurring in the three vegetation types is presented in table 8. Only summer rainfall events are considered, since winter rainfall and snow events have uniformly low intensities (generally less than 0.5 inch per hour).

Intensity-Duration-Frequency Characteristics

The curves in figures 5, 6, and 7 are for recurrence intervals of 2 to 50 years and summer storm durations of 5 to 360 minutes. Curves are linear regression of maximum annual intensities on a transformation of recurrence intervals. The r^2 values ranged from 0.870 to 0.993 (table 9). Return period intensity values for 24 years and longer were determined by linear interpolation. As such, these must be used with caution. Note that the recurrence interval is the average interval during which an intensity of a given duration will recur as an annual seasonal maximum.

The differences of regression slopes among vegetation types were tested for each line interval using covariance analysis. The intensity for 5 minutes' duration of a storm of 25 year recurrence was calculated to be 6.4 inches per hour at the pine station, 6.2 inches per hour at the alligator juniper station, and 4.3 inches per hour at the Utah juniper station. The projected intensities were neither consistent nor statistically significantly different among vegetation types for durations of 15 minutes or longer.

Using a similar analytical approach, Fletcher et al. (1981) found differences in regression slopes among zones in a Utah barometer watershed. However, much of their difference may be attributed to averaging different number of gages in each zone to calculate storm maximum intensities. In the 23 years of record, the greatest intensity for a duration of 15 minutes was 3.6 inches. Intensity of over 3 inches occurred on three occasions. No storm exceeded an intensity of 2.1 inches per hour for one hour duration and only one storm, in the alligator juniper, achieved an intensity of 3.2 inches per hour for 30 minutes' duration. At high intensities and long durations, the records are very similar in the three vegetation types.

The average intensity of summer rainstorms in each of the vegetation types are shown in table 10. Large storms (in terms of precipitation amount) have greater average intensities. Further, in the >1.0 inch size class in all time intervals, average intensities are of the order Utah juniper > alligator juniper > pine. In the 0.76 to 1.0 inch size class, in time intervals of 120 minutes or less, the intensities by vegetation type change to the order alligator juniper > pine > Utah juniper. In the 0.51 to 0.75 inch size class, in each time interval, intensities at Utah and alligator watersheds are about equal but greater than in the pine.

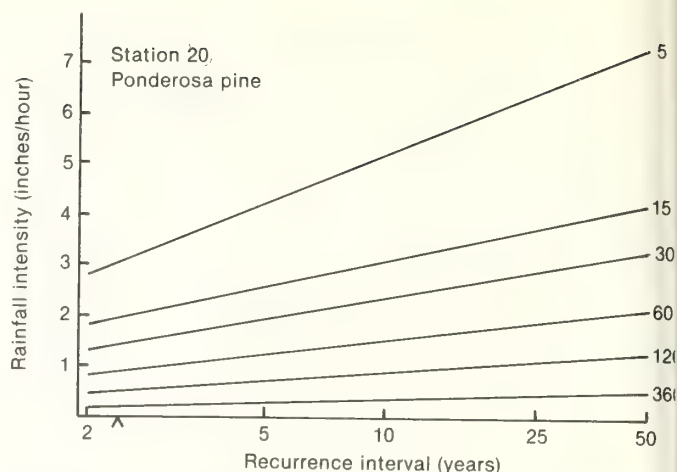


Figure 5.—Rainfall intensity-duration-frequency curves for ponderosa pine type, Beaver Creek watershed, Arizona. Based on 23 years of record.

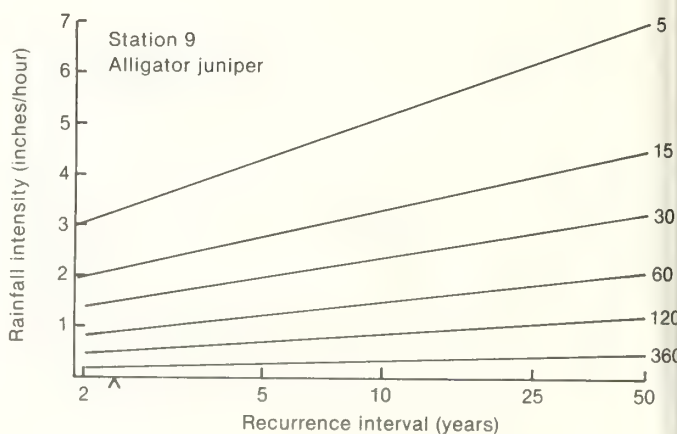


Figure 6.—Rainfall intensity-duration-frequency curves for alligator juniper type, Beaver Creek watershed, Arizona. Based on 23 years of record.

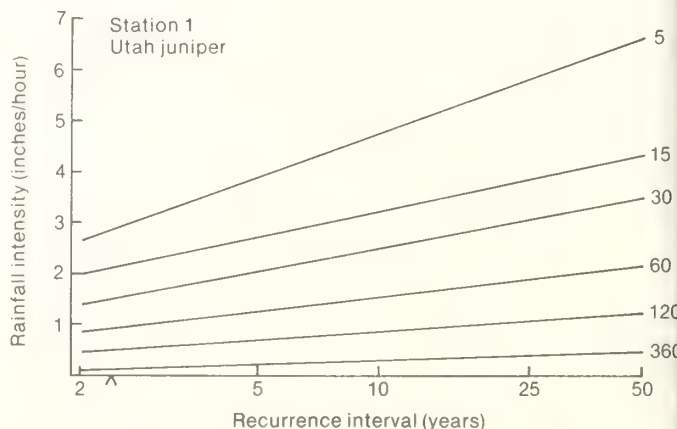


Figure 7.—Rainfall intensity-duration-frequency for Utah juniper type, Beaver Creek watershed, Arizona. Based on 23 years of record.

Table 8.—Storm intensity class frequencies for summer storms ≥ 0.25 inches. Summer season (May-September) for years 1958-1980. Three gages, one each on Utah juniper (U), alligator juniper (A), and ponderosa pine (P) vegetation type. Beaver Creek watersheds, Arizona 1958-1980

Duration (minutes)	Veg. type	Storm intensity class (inches per hour)							
		$\leq .5$	.6-1.0	1.1-1.5	1.6-2.0	2.1-2.9	3.0-3.9	4.0-4.9	≥ 5.0
5	P	76	62	45	23	24	6	2	3
	A	53	42	32	35	31	13	6	2
	U	45	41	36	25	21	9	2	3
15	P	103	60	28	11	14	2	0	0
	A	72	59	66	26	14	3	0	0
	U	59	57	34	17	8	3	0	0
30	P	157	50	17	7	3	0	0	0
	A	105	67	24	5	3	1	0	0
	U	95	50	17	7	4	0	0	0
60	P	183	24	4	2	0	0		
	A	142	31	5	1	1	0		
	U	125	17	4	1	0	0		
120	P	172	5	1	0	0			
	A	136	8	1	0	0			
	U	111	6	1	0	0			
360	P	82	1	0					
	A	61	1	0					
	U	53	0	0					

Table 9.—Regression characteristics of annual maximum rainfall intensities for durations of 5 to 360 minutes at Utah juniper, alligator juniper, and ponderosa pine precipitation stations in relation to frequency factor K

Station	Duration	Intercept	Slope	r ²	SE
U. juniper	5	2.837	1.4698	0.9783	0.193
	15	2.085	0.8613	0.9630	0.149
	30	1.478	0.7881	0.9815	0.095
	60	0.912	0.4885	0.9760	0.068
	120	0.510	0.2711	0.9725	0.040
	360	0.192	0.1055	0.9583	0.019
A. juniper	5	3.273	1.4452	0.9931	0.107
	15	2.120	0.8309	0.9672	0.135
	30	1.507	0.6683	0.9517	0.133
	60	0.911	0.4518	0.9230	0.115
	120	0.511	0.2764	0.9103	0.077
	360	0.191	0.1169	0.8784	0.038
P. pine	5	3.038	1.6625	0.9627	0.289
	15	1.922	0.8866	0.9467	0.186
	30	1.396	0.7383	0.9656	0.123
	60	0.878	0.4935	0.9860	0.052
	120	0.509	0.2986	0.9377	0.068
	360	0.206	0.1321	0.8703	0.045

Correlations Among Gages

Summer storms are relatively small, and are erratic in their tracking patterns as compared to the broad frontal systems in winter. Because of this, amounts of precipitation received on a particular forest type are more nearly the same in winter than in the summer.

Three gages in the pine type, chosen for their wide spread location and length of record, illustrate this phenomenon. A correlation analysis was performed among the three gages using the yearly seasonal and annual precipitation for 18 consecutive years as the

variables. The gages used (A, B, C) are indicated in figure 2.

Correlations among gages were all statistically significant at the 0.05 level. The correlation matrix is shown below:

Gage combination	R ² values		
	Annual	Winter	Summer
A,B	0.91	0.96	0.61
A,C	0.92	0.95	0.64
B,C	0.98	0.99	0.73

Table 10.—Average intensity (inches/hour) of storms for four storm classes—summer only, Beaver Creek watersheds, Arizona 1958-1980

Time interval (minutes)	Utah juniper Size class (inches)				Alligator juniper Size class (inches)				Ponderosa pine Size class (inches)			
	.25-.50	.51-.75	.76-1.00	> 1.00	.25-.50	.51-.75	.76-1.00	> 1.00	.25-.50	.51-.75	.76-1.00	> 1.00
5 Mean	0.98	1.59	1.60	2.64	1.01	1.74	2.26	2.26	0.87	1.23	2.05	1.76
SE	.077	.174	.230	.312	.074	.163	.264	.293	.053	.205	.297	.272
15 Mean	.64	1.08	1.19	2.05	.64	1.12	1.64	1.75	.59	.76	1.35	1.51
SE	.038	.088	.177	.211	.038	.084	.163	.209	.030	.090	.138	.238
30 Mean	.40	.70	.80	1.53	.40	.70	1.07	1.35	.39	.50	.94	1.14
SE	.021	.054	.117	.175	.021	.046	.096	.169	.018	.046	.095	.186
60 Mean	.22	.38	.45	.93	.22	.39	.63	.91	.22	.32	.54	.72
SE	.012	.027	.052	.111	.012	.022	.047	.108	.009	.024	.047	.120
120 Mean	.12	.21	.27	.54	.12	.21	.34	.51	.12	.19	.29	.44
SE	.007	.013	.022	.067	.006	.011	.023	.063	.005	.012	.021	.073
360 Mean	.05	.08	.11	.23	.05	.08	.13	.21	.05	.07	.10	.19
SE	.004	.005	.007	.027	.003	.005	.009	.043	.003	.004	.009	.046

The effect of season on correlation between gages is apparent. All summer correlations are low, even though gages B and C are only 2.6 miles apart. Topography and storm patterns appear to be important factors in determining summer precipitation at a given point.

Temperature

Monthly mean temperature from a representative station in each vegetation type over a 23-year period is shown in figure 8. As expected, highest mean temperatures occur in July, with August slightly warmer than June. The coldest month is January; December is slightly colder than February except in the pine type.

Temperature differences among vegetation types may be explained in terms of elevation. A comparison of long term averages of annual mean temperatures at

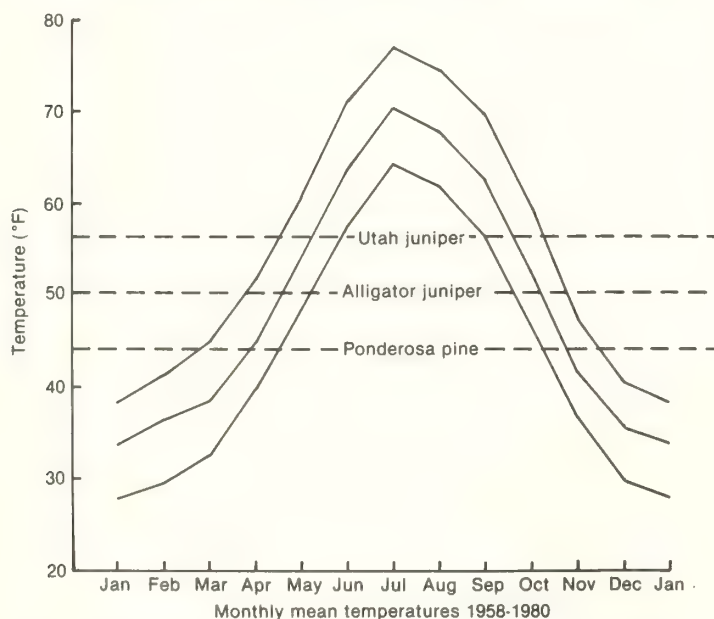


Figure 8.—Monthly mean temperatures of three stations representing three vegetation types on the Beaver Creek watersheds. Values are means of daily record from 1958 through 1980. Horizontal dashed lines are means of monthly values.

46 stations throughout Arizona (National Climatic Center 1980) illustrates the elevation effect. A parabolic curve fits the data. A regression of annual mean temperature on elevation (fig. 9) yielded:

$$\hat{T} = 73.08 - 1.954E - 0.2494E^2$$

where $\hat{T}$ is annual mean temperature (°F) and E is elevation in thousands of feet. The regression had an r^2 value of 0.9406. The three Beaver Creek stations were all uniformly less than 1° F below the regression value. Stations used in the regression ranged in elevation from 191 to 7,320 feet.

Mean monthly diurnal temperature fluctuations were greatest in June for all three types and least in December, February, or March. Diurnal fluctuations are greater every month in the pine type than in the juniper types. Extreme mean monthly diurnal fluctuations in the pine type are 38.3° F in June and 27.4° F in March; in the alligator juniper type they are 33.7° F in June and 23.4° F in January; in the Utah juniper they are 30.7° F in June and 25.4° F in December. For the year, the monthly mean diurnal fluctuations average 27.4° F in both the Utah and alligator juniper, and 31.0° F in the ponderosa pine type. Beschta (1976) also found greatest diurnal fluctuations in summer, and increasing diurnal fluctuation with increased elevation.

Relative Humidity

Average humidity (1972-1975) is highest in pine, intermediate in alligator juniper, and lowest in Utah juniper (table 11). This relationship is consistent with the precipitation and temperature differences among the three types. Humidity values for alligator juniper are not consistently higher than for Utah juniper. Mean maximum humidity is higher in most months in the alligator juniper, but mean minimum humidity is slightly higher in the Utah juniper.

The monthly and seasonal trends in relative humidity are similar to those found for the precipitation data. On all three vegetation types, June has the lowest mean

Table 11.—Mean monthly maximum and minimum relative humidity (percent) for stations in Utah juniper and alligator juniper woodlands, and in ponderosa pine forests (WY 1972 through 1975), Beaver Creek watersheds, Arizona

Month	Utah juniper				Alligator juniper				Pine			
	Mean max.	SD	Mean min.	SD	Mean max.	SD	Mean min.	SD	Mean max.	SD	Mean min.	SD
Jan.	86.0	15.1	38.0	15.2	82.0	10.1	35.8	13.4	95.0	4.7	49.3	14.3
Feb.	78.3	10.7	32.3	4.8	82.8	18.0	36.0	12.6	90.5	9.3	44.0	17.5
Mar.	86.5	14.9	40.0	15.0	85.5	25.6	39.5	15.9	92.3	7.0	48.0	20.8
Apr.	64.5	7.1	26.0	4.1	72.5	16.9	28.8	6.7	87.3	11.6	39.8	12.8
May	51.8	14.6	20.5	7.2	58.0	20.1	20.0	3.7	77.0	18.7	27.3	9.9
June	46.3	24.4	18.3	10.0	52.5	14.0	18.8	3.6	70.5	18.9	25.8	11.1
July	73.0	7.8	23.5	5.9	77.5	12.3	24.0	4.2	88.5	9.8	32.8	6.3
Aug.	63.3	16.3	23.0	10.2	70.3	6.6	21.5	3.0	92.8	4.8	33.0	9.0
Sept.	66.5	12.7	24.3	8.0	70.3	11.6	22.5	3.1	94.0	6.7	35.0	6.7
Oct.	66.5	18.3	31.8	20.3	73.0	12.4	26.8	9.8	92.3	6.0	43.0	17.3
Nov.	73.0	20.6	35.0	20.6	70.5	12.6	27.5	7.2	92.0	7.4	43.3	14.9
Dec.	80.5	9.1	31.0	13.3	80.0	10.6	28.0	5.2	96.8	1.5	43.5	8.2
Average	69.7		28.6		72.9		27.4		89.1		38.7	
SD	12.5		7.8		9.9		6.7		7.7		7.8	

maximum and minimum values while December-March have the highest mean maximum values. Similar trends in relative humidity have been reported by Beschta (1976) for ponderosa pine in central Arizona.

CONCLUSIONS

The data presented in this paper, collected on the Beaver Creek watersheds, are shown as a continuum of precipitation and temperature regimes in Arizona and New Mexico. Values are similar to those reported by Beschta (1976); thus they are applicable to the continuous ponderosa pine forests of the Coconino and

Mogollon Plateaus in Central Arizona, and are related to climatic regimes throughout Arizona and New Mexico. However, small, isolated ponderosa pine forests could have quite different precipitation and temperature regimes.

Because western New Mexico and the Mogollon Rim country of Arizona not only contain similar vegetation (Lanner 1975, Schubert 1974, Tueller and Clark 1975) but are also influenced by the same weather patterns, the data can be used with some limitations by foresters in western New Mexico. In both areas, winter storms move east or northeast from the Pacific Ocean. Most of this precipitation falls in the mountains of central and southwestern Arizona and western New Mexico (Jameson 1969). Both areas receive summer precipitation from storms originating in the Gulf of Mexico (Sellers and Hill 1974), and receive very little precipitation in May and June. The climatic regime of eastern New Mexico is similar to that of the Great Plains, where most of the annual precipitation falls in the spring and summer (Jameson 1969, National Climatic Center 1980).

Southwestern Colorado and southern Utah have precipitation patterns similar to those of western New Mexico and north-central Arizona. The vegetation is similar also, and the climatic data presented here are related to the dry spring areas of these states.

With supplementation by local climatic records the information presented here can be used by managers for road and culvert planning and to help predict sediment yields from various management activities. In addition, long-term climatic records are often used as input for models that predict yields of herbage, timber, and water under alternative management prescriptions.

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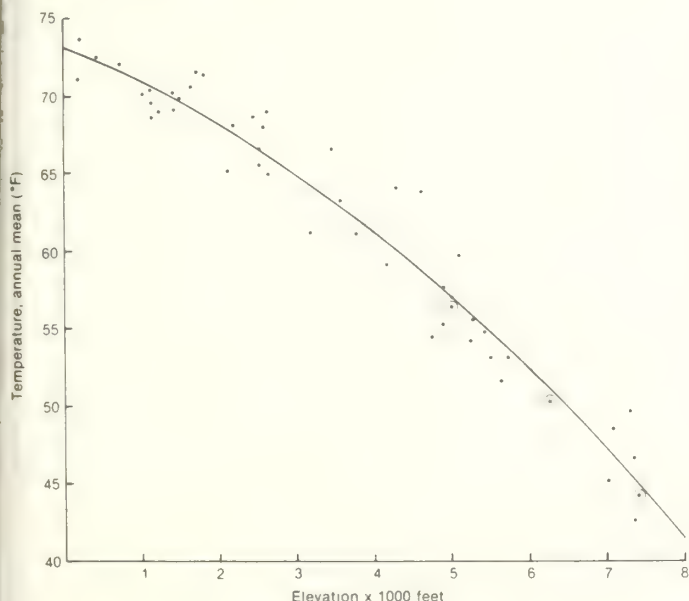


Figure 9.—Regression relation between annual mean temperature and elevation in Arizona. Data include all stations in Arizona with long-term records as reported in annual climatic summary (National Climatic Center, 1980). Beaver Creek stations are identified by $\odot$.

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Precipitation and temperature characteristics of the juniper woodlands and ponderosa pine types as represented on the Beaver Creek experimental watersheds are described using 23 years of record. Average storm size is greater in ponderosa pine than in juniper, but maximum annual intensities are about the same for durations exceeding 15 minutes.

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Rocky
Mountains



Southwest



Great
Plains

U.S. Department of Agriculture
Forest Service

Rocky Mountain Forest and Range Experiment Station

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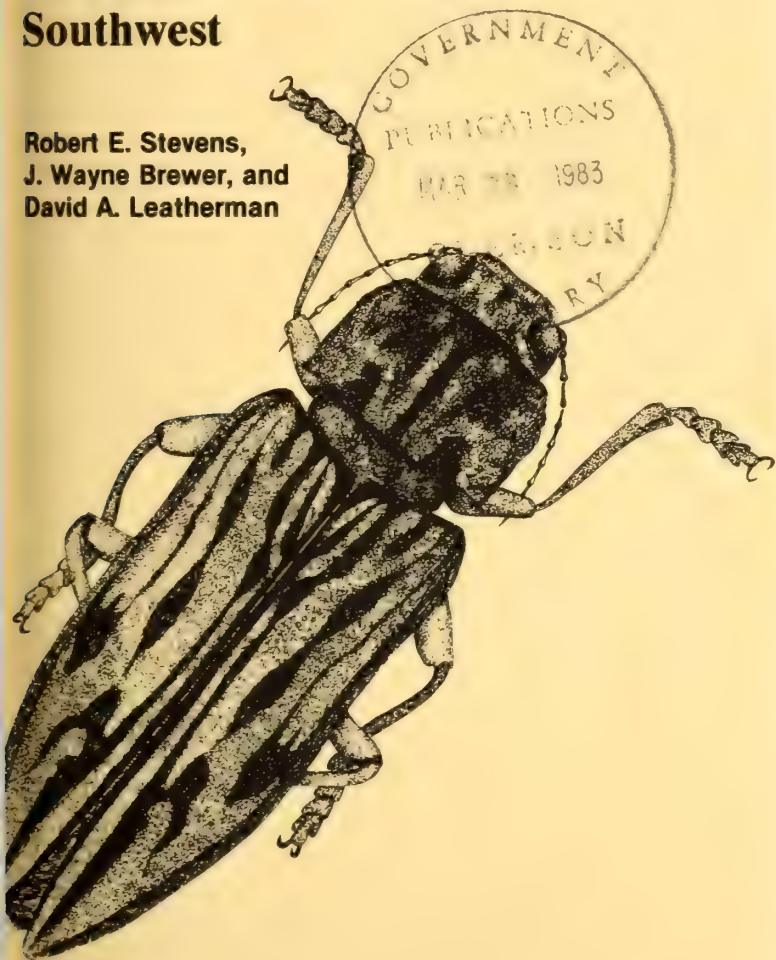
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3, 581 RM-94

Insects Associated with Ponderosa Pine in the Rocky Mountains and the Southwest

**Robert E. Stevens,
J. Wayne Brewer, and
David A. Leatherman**



**General Technical Report RM-94
Rocky Mountain Forest and
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Forest Service
U.S. Department of Agriculture**

Abstract

Ponderosa pine serves as a host for a wide variety of insects. Many of these, including all the particularly destructive ones in the area, are discussed in this booklet. Included are a key to the major insect groups, an annotated list of the major groups, a glossary, and a list of references. This report supersedes USDA Forest Service General Technical Report RM-75.

Insects Associated with Ponderosa Pine in the Rocky Mountains and the Southwest

Robert E. Stevens¹, J. Wayne Brewer², and David A. Leatherman³

¹*Entomologist, Rocky Mountain Forest and Range Experiment Station. Station's headquarters is in Fort Collins, in cooperation with Colorado State University.*

²*Professor, Department of Zoology and Entomology, Colorado State University, Fort Collins.*

³*Entomologist, Colorado State Forest Service, Colorado State University, Fort Collins.*



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INTRODUCTION

This booklet is about the insects associated with ponderosa pine, a major component of forests throughout the West. Its focus is the central Rocky Mountain area, including portions of Wyoming, Colorado, and South Dakota, as well as Arizona and New Mexico. It replaces USDA Forest Service General Technical Report RM-75, "Insects Associated with Ponderosa Pine in Colorado."

While many hundreds of kinds of insects can be found in the ponderosa pine forest, we are mainly interested in those that have close ecological ties with the pines—those that live in and on the trees themselves. Many of these insects are injurious to the trees and are thus particularly important to the landowner and the land manager.

Organization.—The booklet is divided into five sections:

1. A table listing groups of insects commonly seen in the ponderosa pine forest.
2. A key to insect-caused tree damage.
3. An annotated list of the groups and species referred to in sections 1 and 2.
4. A list of references, or sources of additional information.
5. A glossary of specialized terms.

We have kept the text as brief as possible. Readers who need help in identifying insects or recommendations on insect control should consult with specialists associated with federal, state, and local government forestry organizations. Consultation on control methods is particularly desirable, as recommended procedures are frequently updated.

References.—There is abundant literature on the various insect groups. The book by Furniss and Carolin (1977)⁴ is currently the best single reference on western forest insects and contains detailed discussions of most insect species dealt with here. Essig (1958) and Borror et al. (1981) are also good sources of general entomological information; Borror and White (1970) is a good field guide to the major groups of insects.

⁴*This and similar citations refer to items in Section 4—References.*

Insect Names.—Insects all have scientific names, and the more important species also have common names. The common names are used where possible in this booklet, but where there is none, we are obliged to use the scientific name only. The following three paragraphs describe the system of scientific names and are included to help the reader better understand it.

Insects are generally categorized into 26 major groups, or orders. Only 10 of these orders are commonly seen in the ponderosa pine forest (section 1). Orders are further subdivided into families, genera (singular genus), and species (singular also species). Family names always end in “-idae.” Genus and species names are always italicized in print or underlined when handwritten or typed.

The genus and species, along with the author (the scientist who named the insect species), make up the scientific name. For example, the scientific name for the mountain pine beetle is *Dendroctonus ponderosae* Hopkins. Sometimes the author's name is shown in parentheses: *Dendroctonus rufipennis* (Kirby). This indicates that the species was originally placed in another genus. For brevity, genus names are commonly abbreviated after the first use; for example, *D. ponderosae* Hopkins. Oftentimes also the author's name is dropped after initial use.

In rare instances, an additional element is required in a scientific name to identify a subspecies. For example, the scientific name for the pine tortrix is *Choristoneura lambertiana ponderosana* Obraztsov.

Insect life stages.—All insects pass through a series of distinctive developmental stages. Most that we are concerned with pass through four life stages: egg, larva (grub, caterpillar, maggot, etc.), pupa or resting stage, and adult. Others have an abbreviated pattern of egg, nymph (resembles adult but lacks wings), and adult.

Use of this booklet.—Many readers will use this booklet to find out what kinds of insects are damaging their trees. The best way to do this, once the insects or damage have been found, is as follows:

1. Locate the proper part of the key (section 2) for symptoms
2. Use the key to tentatively identify the kind of insect.
3. Look up the insect in the annotated list (section 3).
4. If desired, look up extra reading material in the references section.

SECTION 1

COMMON GROUPS OF INSECTS ASSOCIATED WITH PONDEROSA PINE⁵

Common names	Order	Main habitats
Grasshoppers and others	Orthoptera	On ground and foliage
Termites	Isoptera ⁶	In decaying wood
Earwigs	Dermaptera ⁶	In litter, under bark
True bugs	Hemiptera	On foliage, cones
Aphids, scales, and Others	Homoptera	On foliage
Lacewings and snakeflies	Neuroptera ⁶	On foliage, branches
Beetles and weevils	Coleoptera	In or on foliage, cones or branches, in cambium area, or in wood
Moths and butterflies	Lepidoptera	Larvae in or on foliage, shoots, cones, or cambium area
Flies and midges	Diptera	Larvae in foliage, shoots, or cones
Ants, bees, sawflies, others	Hymenoptera	Larvae on foliage or wood; adults on or around trees

⁵*Groups of insects (e.g., dragonflies) found in the forest but not particularly associated with the trees are excluded.*

⁶*Orders that do not include species commonly destructive to living trees.*

SECTION 2

KEY TO INSECT-CAUSED TREE DAMAGE

Index

	Page
Damage to Cones	4
Damage to Shoots, Twigs, or Terminals	4
Damage to Foliage (Needles) Only	5
Damage to Trunk, Entire Tree, or Wood	6

Damage to Cones

1. Entire cones distorted and/or discolored; may be pitchy; interior portions mined or otherwise damaged	
..... cone moths, <i>Dioryctria</i> , etc.	31
..... cone beetles, <i>Conophthorus</i>	27
..... cone weevils, <i>Conotrachelus</i>	18
2. Cone scales and/or seeds stuck together; small maggots without distinctive head regions	cone midges 35
3. Seeds hollowed out or inside material shrunk; cones appear normal	seed chalcids 39
..... cone bug, <i>Leptoglossus</i>	8
4. Larvae and/or pupae in cone pith; larvae bore into seeds	seed moths, <i>Cydia</i> 32

Damage to Shoots, Twigs, or Terminals

1. Terminals only affected. No fading; needles more or less shortened, not distorted; pith mined out; terminal thickened; terminal may continue to live although superseded by lateral(s)	
..... shoot borer, <i>Eucosma</i>	32
2. Terminals and/or laterals affected	
a. Needles faded	
(1) Shoots partly mined out	
..... pitch midges, <i>Cecidomyia</i>	35
..... twig weevils, <i>Magdalis</i>	18
(2) Shoots completely mined out; wood destroyed ..	
..... tip moths, <i>Rhyacionia</i>	32
(3) Cambial area only mined out	twig beetles 27

(4) Masses of pitch produced externally on shoots . . .	
..... twig borers, <i>Dioryctria</i>	31
..... pitch nodule moths, <i>Petrova</i>	32
b. No fading; needles badly swollen at bases	
..... needle midges	35
c. No fading; shoots covered with masses of fluffy	
white wax woolly aphids, <i>Pineus</i>	9

Damage to Foliage (Needles) Only

1. Foliage chewed, thin, or sparse	
a. Masses of silken webbing mixed with frass,	
associated with defoliation	
(1) Throughout crown; webbing relatively sparse . . .	
..... budworms, <i>Choristoneura</i>	33
..... needle-sheath miner, <i>Zelleria</i>	35
(2) Throughout crown; webbing a dense, nearly	
spherical, frass-filled mass	
..... pine webworm, <i>Tetralopha</i>	31
(3) Mainly in tree tops; heavy silk webs	
..... tiger moths, <i>Halisidota</i>	29
b. Little or no webbing produced	
(1) Caterpillars, often clustering together	
..... sawflies	37
..... pine butterfly, <i>Neophasia</i>	29
..... pandora moth, <i>Coloradia</i>	29
(2) Not caterpillars; insects often not seen; "bites"	
taken out of needles grasshoppers	7
..... weevils	16
2. Needles faded; mined out from within	
..... ponderosa pine needle miner, <i>Coleotechnites</i>	33
3. Needles badly distorted, shortened, bases swollen	
..... needle midges	35
4. Sucking insects, usually attached to or appearing to rest	
quietly on needles scales	9
..... aphids	9
..... cicadas	11

Damage to Trunk, Entire Tree, or Wood

Page

- | | |
|--|----|
| 1. Pink or reddish frass in bark crevices and around base of tree; pitch tubes may be present; galleries in cambial area; entire tree eventually fades | 21 |
| bark beetles, <i>Dendroctonus</i> , <i>Ips</i> , etc. | |
| 2. White frass in bark crevices in basal 0.5 m of tree; no pitch tubes; fungus-stained galleries penetrate directly into wood; often associated with successful bark beetle attack; also in lumber | 27 |
| ambrosia beetles | |
| 3. Large (up to golf ball size) masses of pitch on trunk (sometimes also on larger limbs) | 31 |
| pitch moths | |
| 4. Large larvae, pupae, or adults in cambial area or in wood; found in dead trees, logs, or lumber; tunnels in wood, lumber | |
| a. Tunnels more or less flattened or oval in cross section | 13 |
| roundheaded borers, <i>Cerambycidae</i> | |
| flatheaded borers, <i>Buprestidae</i> | 13 |
| b. Tunnels circular in cross section | |
| horntails, <i>Siricidae</i> | 38 |

SECTION 3

ANNOTATED LIST OF COMMON INSECT SPECIES AND GROUPS ASSOCIATED WITH PONDEROSA PINE

Grasshoppers, Crickets, and Others—Order Orthoptera

Grasshoppers are known for great changes in numbers from one year to another. During outbreaks, feeding damage to a wide variety of plants is possible, including defoliation of young ponderosa pines.

Termites—Order Isoptera

Termites are soft-bodied, fragile insects that usually shun light and are secretive in their habits. They feed on nonliving wood and cause serious damage to structures in many parts of the country. In the forest they help speed decay and decomposition of dead wood. Many species of termites occur in the warm southwest, but only two, *Reticulitermes tibialis* Banks and *R. flavipes* (Kollar) are regularly found in the interior of our area.

Earwigs—Order Dermaptera

Earwigs are scavengers on decaying plant and animal matter. Although sometimes found beneath the bark of dead or dying pines, they do no harm to trees. A large pincer-like structure at the end of the abdomen helps identify this group.

True Bugs—Order Hemiptera

Many bugs are plant feeders (also many species are predators on other insects), and are readily seen and collected as they rest on ponderosa pine foliage and branches. They are generally good fliers and have mouthparts adapted for piercing and sucking. A few species are closely associated with the trees; many others feed on grass, herbs, and other vegetation.

Leaf-footed Bugs—Family Coreidae

One species of leaf-footed bug, *Leptoglossus occidentalis* Heidemann (fig. 1), is a large (about 15 mm long), conspicuous insect that feeds on the cones of several different conifers, including ponderosa pine. The beak is inserted through the cone scales into individual seeds, and the material within is dissolved and sucked up. A damaged seed is not readily distinguishable from a sound one; however, it will not produce a normal seedling. Under field conditions, it is doubtful that *L. occidentalis* causes enough damage to inhibit regeneration.



Figure 1.—*Leptoglossus occidentalis*, a seed-eating bug. Bug is about 15 mm long.

Plant Bugs—Family Miridae

Plant bugs and other small bugs are common on pines and are readily collected by beating foliage over a cloth. Mirids are small (2–9 mm), fragile, and usually inconspicuous. Most are plant feeders, although none is known to feed on conifers. Members of one genus, *Neoborella*, feed on pine dwarf mistletoe.

Aphids, Scales, and Others—Order Homoptera

Members of the Homoptera are similar to the Hemiptera in that they have four wings (at least during some developmental stage) and sucking mouthparts.

Scale insects are a common and more economically important group of Homoptera. Many species of these insects infest ponderosa pine. The pine needle scale, *Chionaspis pinifoliae* (Fitch), (fig. 2) is a common species, and the Prescott scale, *Matsucoccus vexillorum* Morrison, is occasionally a pest. Woolly aphids, genus *Pineus*, are common on succulent new shoots in early summer and produce large amounts of conspicuous silky-looking wax. Palmer (1952) provides keys and descriptions of Colorado aphids. Other genera reported include *Cinara*, *Essigella*, *Eulachnus*, and *Schizolachnus*.

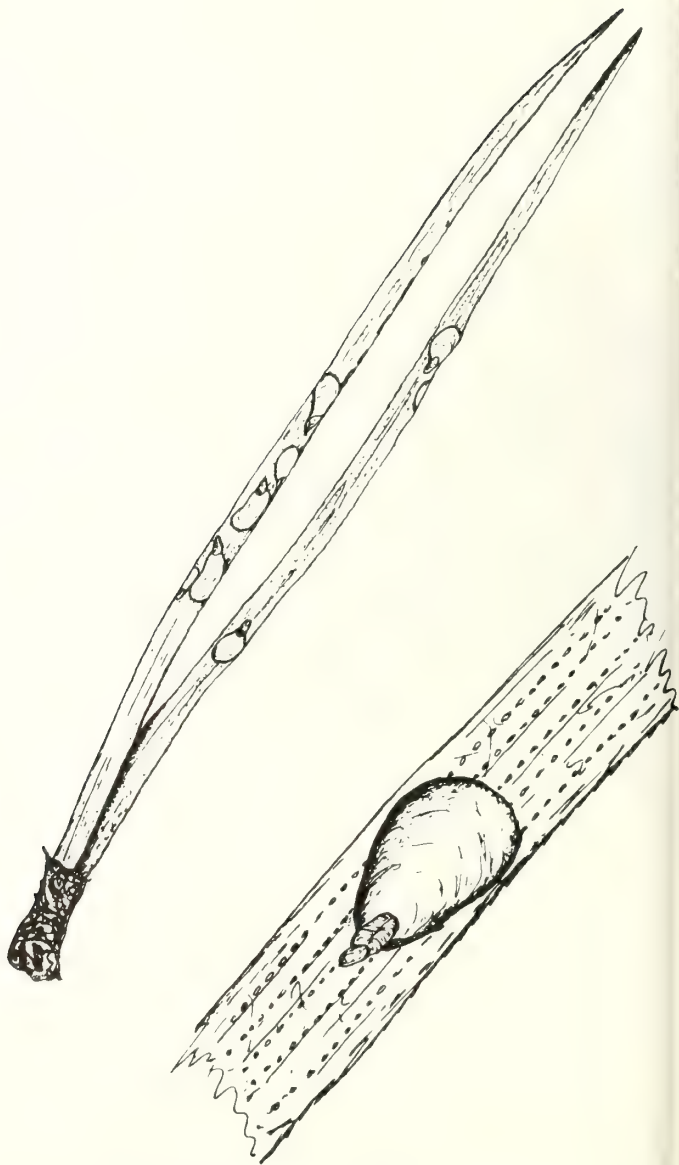


Figure 2.—Pine needle scales, 2 to 2.5 mm long.

Cicadas are a group of large Homoptera that are common in the pine forest, although the adults usually do no more than rest in pine trees. Cicada nymphs (17-year locusts, etc.) live from several to many years in the soil, feeding on roots. Adults (fig. 3) lay eggs in branches and shoots of many kinds of trees and shrubs, sometimes causing considerable shoot breakage.



Figure 3.—Adult cicada resting on twig. Insect is 20-25 mm long.

Lacewings and Snakeflies—Order Neuroptera

Many members of this order are predators of pest insects in both immature and adult stages and are considered beneficial. Lacewings (fig. 4a), are light green or brown. Adult snakeflies (fig. 4b), as their name indicates, resemble serpents. Both groups have large but delicate wings. Aphids and butterfly or moth larvae are common prey.

Along with other natural enemies, insect predators and parasites are often important in holding populations of pest insects under control. Sometimes this "balance of nature" gets upset, and one or another kind of insect will reach high population levels. High population levels of pest insects are called "outbreaks," or "epidemics."

In some instances, natural enemies can be favored, or even manipulated. This is "applied biological control," a desirable approach to keeping insect pests below damaging levels.

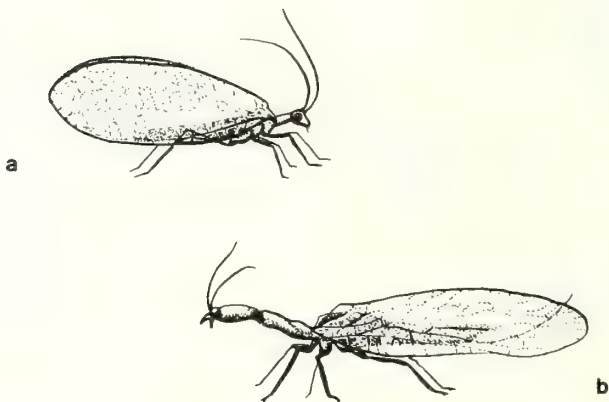


Figure 4.—Adults of (a) lacewing and (b) snakefly. Insects are in 15 mm long.

Beetles and Weevils—Order Coleoptera

Beetles are possibly the most numerous and most destructive group of insects associated with ponderosa pine. The bark beetles, family Scolytidae, are important tree-killers. Larvae of roundheaded and flatheaded borers, families Cerambycidae and Buprestidae, commonly colonize recently killed trees, feeding in the cambial area and often later tunneling into the wood. Larvae of weevils, family Curculionidae, infest cones and root collars of dying trees, and adults often feed on pine foliage.

Flatheaded Borers, Metallic Wood Borers—Family Buprestidae Longhorned Beetles, Roundheaded Wood Borers, Sawyers— Family Cerambycidae

Insects belonging to these two families (figs. 5 and 6) have similar ecological roles with respect to ponderosa pine, and tree-infesting species have similar life cycles and habits. Adult females of both families lay eggs in niches in the bark of dying or recently killed trees. Larvae tunnel in the cambial area and may subsequently move into the wood. Larval galleries make irregular patterns and become larger as the insects grow. Buprestid larvae have a typical "horseshoe nail" shape; cerambycid larvae are less flattened. Life cycles may extend over several years. Buprestids and cerambycids are often responsible for chewing noises heard coming from infested pine firewood. Borer adults occasionally emerge in houses from studs sawed from fire-killed timber that was infested while still in the woods, or from logs used in rustic cabins. Larval galleries are packed with frass and wood shavings; emergence tunnels and holes in the bark through which the adults exit the tree are open, round or oval in cross section, and up to 5 mm in diameter. Important genera of these two families include *Monochamus*, *Canonura* (= *Acanthocinus*), *Ergates*, *Asemum*, and *Tragosoma* (Cerambycidae); and *Chalcophora*, *Dicera*, *Buprestis*, and *Melanophila* (Buprestidae).



a



b

Figure 5. — Longhorned beetle (a) adult, 55 mm long; and (b) larva, 60 mm long, removed from feeding tunnel in wood.

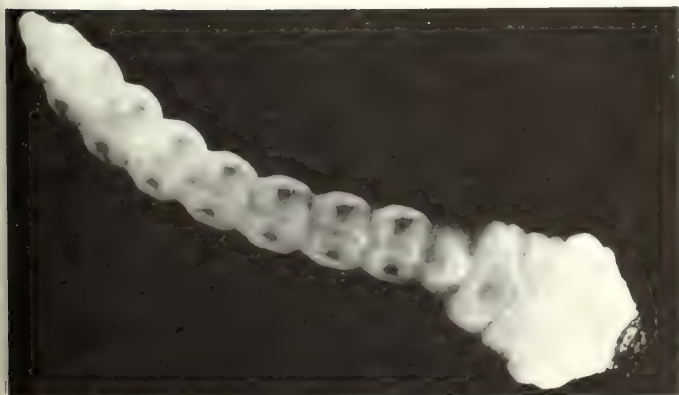


Figure 6.—Metallic wood borer (a) adult, 20 mm long, and (b) horse-shoe-nail-shaped larva, 25 mm long.

Weevils—Family Curculionidae

Weevils, or “snout beetles” (some actually have very short “snouts”), are a large and highly variable group of beetles with an equally wide variety of habits. Many species are found in and on trees, but only four genera are important to us here:

***Scythropus*.**—Weevils of this genus are often responsible for “saw-tooth” feeding seen on pine needles (fig. 7). The adults are somewhat elongate, broad-nosed weevils ranging from 4.5 to 7.5 mm in length. Some species are colorful, ranging from the ashy-white of *S. albidus* Fall to the bronze of *S. californicus* Horn to the metallic blue green or gold of *S. elegans* (Couper). These weevils feed on old needles in the spring and early summer. These insects may be minor pests in ornamental plantings but do not cause economic damage in forest situations.



Figure 7.—Pine needles fed on by *Scythropus* beetles.

***Pissodes schwarzi* Hopkins.**—Found in rare instances infesting the root-collar area of small (< 2 m tall) trees. As a general rule, *P. schwarzi* is not successful in attacking healthy trees, but succeeds only in hosts weakened by some other factor. This and other *Pissodes* weevils pupate in characteristic “chip cocoons” (fig. 8). Entomologists refer to species such as this as “secondary,” as opposed to “primary,” pests. Primary pests colonize apparently healthy hosts. For example, most defoliators are considered “primary,” because the condition of the host tree is not thought to have much to do with whether or not the tree is successfully attacked by the insects. “Secondary” species, such as these weevils, generally do not attack healthy, vigorous trees. Other typically secondary insects include wood boring beetles, turpentine beetles, ips beetles, ambrosia beetles, and horntail wasps.



Figure 8.—*Pissodes* (a) larva, 4.5 mm long; and (b) “chip cocoons”.

***Conotrachelus neomexicanus* Fall.**—This weevil, known as the “ponderosa pine cone weevil,” (fig. 9) has recently been identified as a cone pest. Larvae mine indiscriminately within the cone, reducing its interior to fine sawdust-like frass. Larvae drop to the ground in midsummer, pupate in cells in the soil, emerge in fall to feed on needles and shoots, and overwinter in the adult stage.

Magdalis.—Weevils of this genus develop in twigs and branches. The adults, often colored black, bright metallic blue, or green, are sometimes found on ponderosa pine shoots and foliage. *M. lecontei* Horn is a common species infesting ponderosa pine.

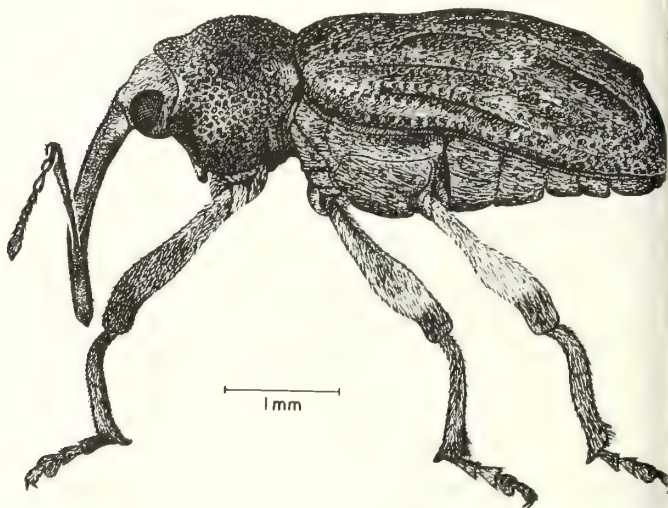


Figure 9.—Adult ponderosa pine cone weevil.

Checkered Beetles or Clerids—Family Cleridae

Several species of clerids (fig. 10) are important bark beetle predators. Clerid larvae operate in the bark beetles' galleries, and adults capture bark beetle adults on the bark surface. Following are the most important species:

Enoclerus sphegeus (Fabricius)—red-bellied clerid

E. lecontei (Wolcott)—black-bellied clerid

Thanasimus dubius Fabricius

T. undatulus (Say)

Darkling Beetles—Family Tenebrionidae

Beetles of this family, highly varied in appearance, are commonly found under the bark in decaying wood of trees killed by bark beetles. Tenebrionids are mostly scavengers. The ones seen most often are small, slender, shiny, dark-red-colored beetles.

Trogositid Beetles—Family Trogositidae (= Ostomidae)

Temnochila chlorodia (Mannerheim), a metallic bluish-green trogositid beetle, is a common bark beetle predator.

Cylindrical Bark Beetles—Family Colydiidae

Although they are common in bark beetle-infested trees, little is known of the precise role(s) these small brown insects play in pines. Members of the genus *Aulonium* inhabit mountain pine beetle galleries, occasionally in large numbers. Some species are said to be predaceous; others scavenge organic matter.

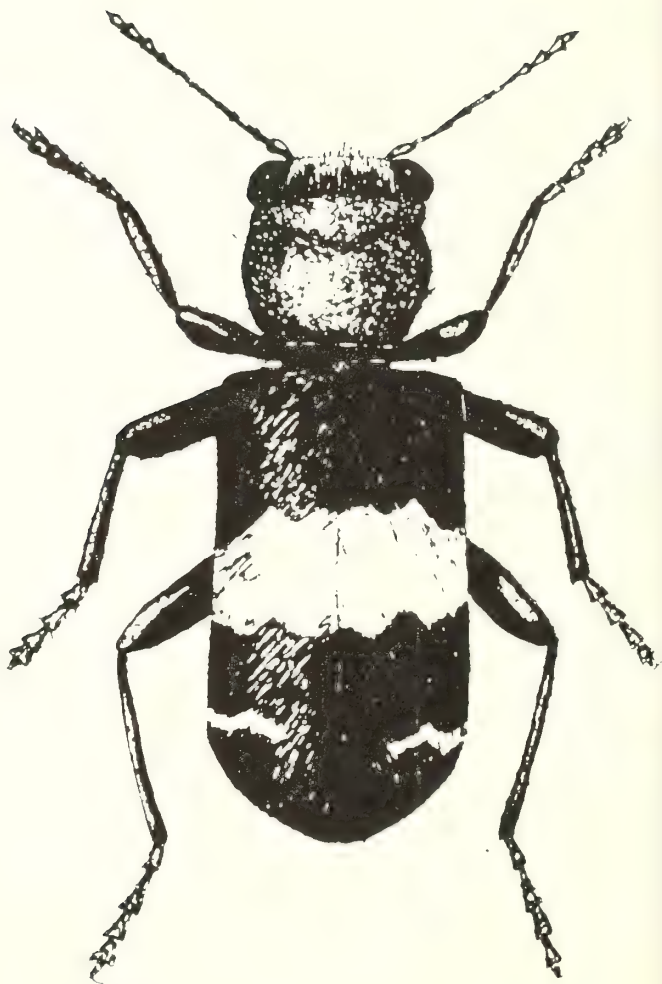


Figure 10.—Adult clerid beetle, about 10 mm long.

Bark Beetles—Family Scolytidae

Bark beetles, especially those in the genus *Dendroctonus*, are one of the most destructive groups of forest insects in western North America. Adults of most genera bore through the bark to lay eggs in galleries (fig. 11) in the cambial area. Larvae generally mine in the same area. Their feeding galleries, in addition to the egg galleries made by the adults, create a lasting pattern of “tracks” on the surface of the wood by which the species can be identified even long after the insects themselves have disappeared.

All the bark beetles carry spores of “blue stain” fungi. These spores, introduced into “beetle trees” when the beetles attack, multiply and effectively block the trees’ water and nutrient conducting systems. Thus, in a “successfully” attacked tree, the beetles and the blue stain fungi combine forces to kill the tree.

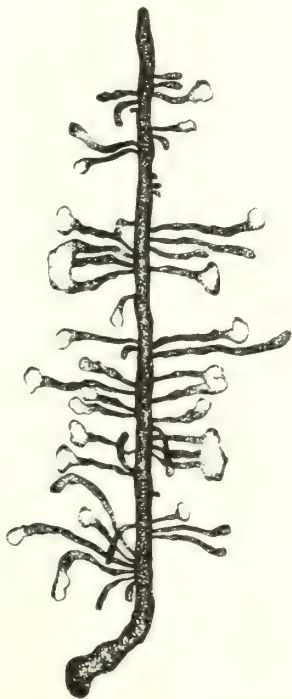


Figure 11.—Mountain pine beetle gallery system; entrance hole at bottom, vertical egg gallery, and horizontal larval galleries. Egg gallery may be up to 80 cm long.

Mountain pine beetle, *Dendroctonus ponderosae*

Hopkins.—This species is a serious enemy of ponderosa pine, particularly in South Dakota, Wyoming, Colorado, and the Kaibab Plateau of northern Arizona. During outbreaks, it can kill thousands of healthy appearing trees annually. In late summer (August, generally), adult beetles bore through the bark and into the cambium area of living trees, mate, and then lay eggs in vertically oriented egg galleries. The eggs (fig. 12a) hatch in a few days and the tiny larvae (fig. 12b) begin feeding outward from the egg gallery, still in the region of the cambium. Pupae (fig. 12c) and adults (fig. 12d) develop at the ends of the larval galleries. Flight and egg laying occur generally during late July and August. Successfully attacked trees, although remaining green until the following summer, are in fact killed within just a few days. The beetle progeny mostly overwinter as small larvae, completing their development and emerging from host trees to renew the cycle the following summer.

Efforts to minimize tree losses caused by bark beetles include killing beetles in infested trees before they are able to emerge to attack green living trees, spraying of individual living high-value trees to prevent beetle attack, and thinning to change conditions in forests that are susceptible to beetle outbreaks.

Western pine beetle, *D. brevicornis* LeConte.—This species is a major pest on the West Coast, sometimes causes problems in Arizona and New Mexico, and is rare in southwestern Colorado. It has distinctive meandering egg galleries, as opposed to the vertically oriented ones of *D. ponderosae*. The larvae, instead of remaining in the cambial area, do most of their mining in the inner and outer bark. Pupation is in the outer bark. Western pine beetle has several (usually around three) annual generations.

Roundheaded pine beetle, *D. adjunctus* Hopkins.—This is a southern species extending from the southwestern U.S. into Mexico and Central America. It is found as far north as southwestern Colorado and has occasionally been a serious tree-killer in unmanaged second-growth ponderosa pine stands in New Mexico. It is often found colonizing trees in conjunction with other *Dendroctonus* species.

Southern pine beetle, *D. frontalis* Zimmerman.—This species, a major pest in the southeastern States and in Mexico and Central America, is also known from southern Arizona and New Mexico. Its life history and habits are similar to those of western pine beetle.

Larger Mexican pine beetle, *D. approximatus* Dietz.—Beetles of this species inhabit pine and spruce in the southern Rockies. It is not aggressive and favors the lower trunk of large-diameter trees already overcome by other bark beetle species. Its egg galleries typically wind and cross each other. The larval mines are wholly within the outer bark.

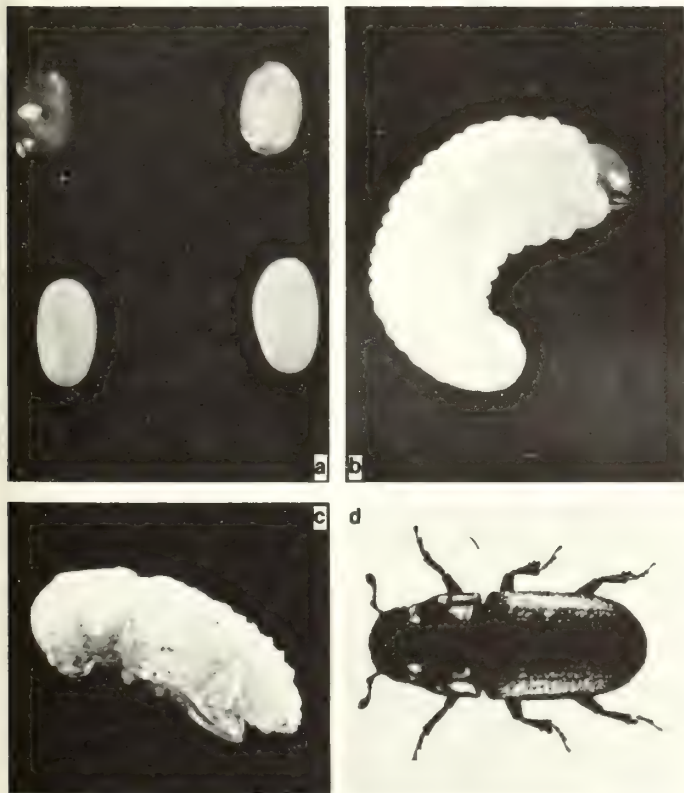


Figure 12.—Bark beetle life stages a. eggs, 1 mm long; b. larva, up to 8 mm long; c. pupa, d. adult, up to 7.5 mm long.

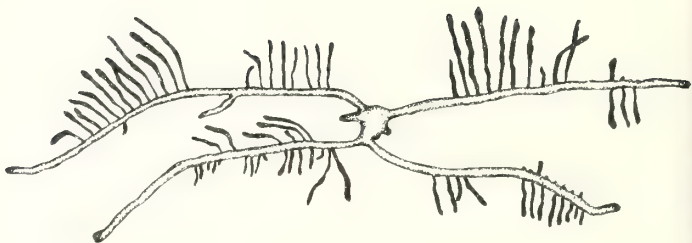
Red turpentine beetle, *D. valens* Le Conte.—While sometimes attacking otherwise healthy trees, this beetle is usually found in the basal (up to about 0.5 m) portion of damaged trees or trees infested with other species of *Dendroctonus*. Turpentine beetles are not usually tree-killers by themselves, but can weaken trees and make them more susceptible to attack by other, more aggressive bark beetles. Turpentine beetles have a tendency to attack trees that have been injured by fire, during logging, road or building construction, and similar kinds of activities. Stumps are also colonized. Large pitch tubes (fig. 13) are characteristic of attacks by this species.



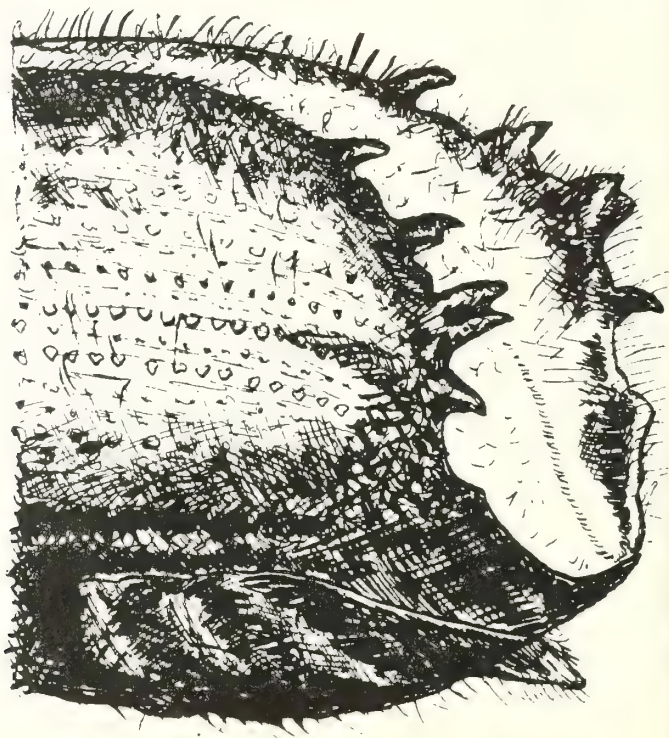
Figure 13.—Pitch tubes at base of tree resulting from attack of red turpentine beetle.

Ips bark beetles; pine engraver beetles, *Ips* spp.—*Ips* beetles (fig. 14) are common in pine forests. Their name is unusual in that it is both a common and a scientific name. *Ips* are often secondary and colonize the upper parts of trees killed by *Dendroctonus* bark beetles. They commonly infest slash, creating piles of frass in bark crevices. Also, fire-scorched trees are often susceptible to *ips* attacks and may, like slash, trigger short-lived outbreaks in standing healthy trees. *Ips* egg galleries (fig. 14a) are readily distinguished from those of *Dendroctonus*, as they are kept free of frass. Adult beetles are also easily separated from *Dendroctonus* by their concave posterior “declivity” (fig. 14b). Important species in ponderosa pine include:

- Ips calligraphus* (Germar)
- I. integer* (Eichoff)
- I. knausi* Swaine
- I. lecontei* Swaine
- I. pini* (Say)



a



b

Figure 14.—Ips beetles (a) gallery system as in a down log, and (b) concave spined declivity of adult. Note central “nuptial chamber” and radiating egg galleries. In a standing tree, gallery is oriented vertically, and may be up to 25 cm long.

***Hylurgops* spp.**—Adults strongly resemble *Dendroctonus*, but have noticeably rougher, less shiny bodies, and are substantially smaller. *H. subcostulatus* (Mannerheim) is known from ponderosa pine. It is also secondary (i.e., not a tree-killer) and is typically found in the basal portions of trees killed by *Dendroctonus*. Early spring-emerging *Hylurgops* beetles are often mistaken for mountain pine beetles.

Twig beetles.—Several genera of small (about 2 mm long) bark beetles sometimes infest ponderosa pine twigs and branches, causing them to flag (i.e., fade). This results in some of the natural pruning that goes on continually in the forest. Usually the infestation proceeds at low level and is inconspicuous; but, at times, high beetle populations develop, and the fading attracts attention. On rare occasions, trunks of small ponderosa pine saplings that are growing poorly can be invaded. Genera involved include *Pityophthorus*, *Pityogenes*, and *Carphoborus*.

Ambrosia beetles.—Ambrosia beetles are a group of bark beetles that bore directly through the bark into the wood, generally in dead or dying trees. Often they follow closely after *Dendroctonus* beetles, colonizing the basal portion of trees killed by the mountain pine beetle, attacking the following summer. The feeding habit of ambrosia beetles is different from other scolytid beetles; the larvae develop in short galleries, or "cradles," (fig. 15) prepared by the adults well within the sapwood. They feed on fungi that colonize the walls of the "cradles." The pinholes and associated stain caused by ambrosia beetles can result in downgrading of otherwise good quality lumber. Several species of the genus *Gnathotrichus* are known from ponderosa pine.

Ponderosa pine cone beetle, *Conophthorus ponderosae* Hopkins.—This small bark beetle is a common enemy of second-year cones. Adults bore into the base of the cone; the cone never reaches normal size and produces no seed. All beetle development takes place within the cone.

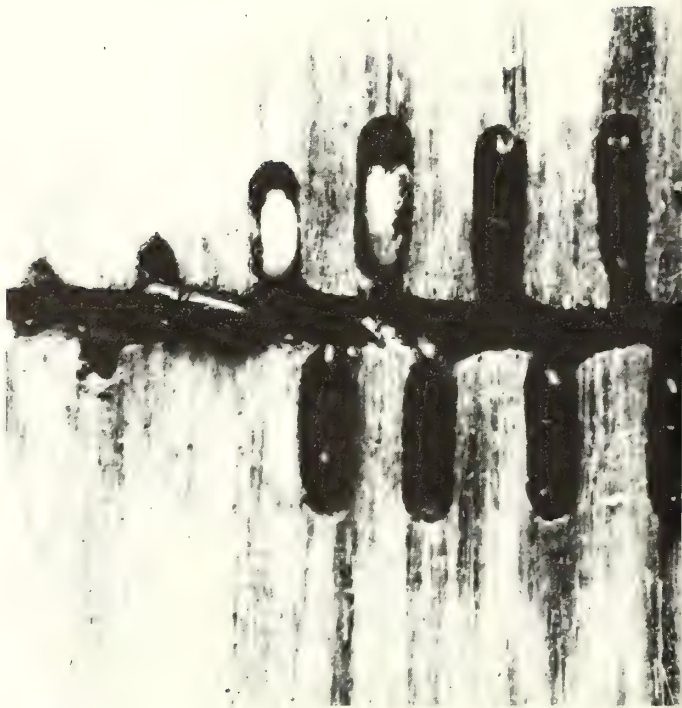


Figure 15.—Ambrosia beetles in “cradles” in wood.

Moths and Butterflies—Order Lepidoptera

Many species of moths and butterflies are closely associated with conifers, and some are destructive pests in the larval or caterpillar stage. The more important groups that feed on ponderosa pine are as follows:

Whites and Sulphurs—Family Pieridae

This family includes a number of destructive agricultural pests. One species, the pine butterfly, *Neophasia menapia* (Felder and Felder), is common throughout western ponderosa pine forests. The medium-sized, mostly white adults are often seen in the summer flitting about the tree tops. The larvae, less commonly seen, are smooth-bodied and are marked with green with white stripes. Populations usually are maintained at low levels but can increase to outbreak proportions and cause considerable damage.

Giant Silkworm Moths—Family Saturniidae

Pandora moth, *Coloradia* spp.—This genus contains two species, *C. pandora* Blake, and *C. doris* Barnes, known to injure ponderosa pine. Larvae of both these species feed on old needles, gregariously at first and individually when mature. Full-grown larvae are large, up to 80 mm long, and usually light yellow-green or gray-green. They have a white stripe running down the center of the back and short, stout black spines on each body segment. Pupation is in the soil. The thick-bodied adults are dark gray with yellow antennae and often bright pink hairs on the hind wing bases and interior margins. The life cycle requires 2 years in the case of *C. pandora*, 1 year for *C. doris*.

Tiger Moths—Family Arctiidae

Larvae of several species of tiger moths (genus *Halisidota*) build heavy webs (fig. 16) in terminals (and occasionally laterals) on pines and other western conifers. From these webs, the larvae move out to feed on the foliage. Little damage appears to result, but the webs are conspicuous and often attract attention. *H. insignis* Hy. Edwards, probably the most common species, overwinters in the larval stage and can be found feeding on warm winter days.

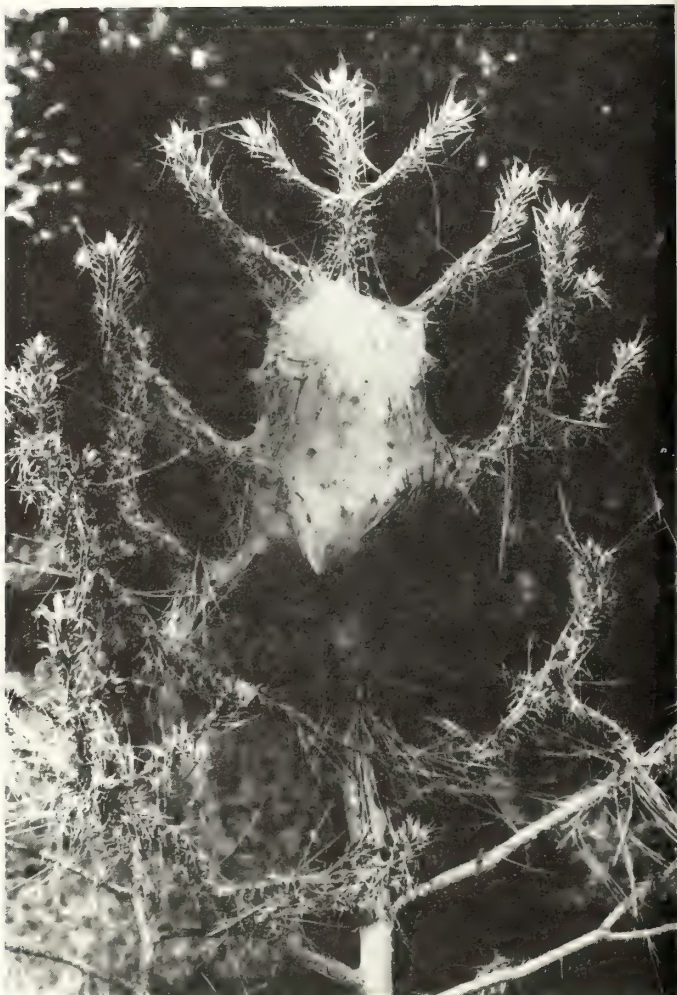


Figure 16.—*Halisidota* web and defoliation caused by feeding larvae.

Pyralid Moths—Family Pyralidae

Several species of the genus *Dioryctria* (fig. 17) infest different parts of ponderosa pine trees. *D. zimmermani* (Grote) is a serious pest of ponderosa pine in plains plantings as well as natural stands. Larval feeding in limbs and boles can result in weakened areas prone to wind breakage. Larvae of *D. cambiicola* (Dyar) and *D. baumhoferi* Heinrich work mainly in branch tips, killing the outer several centimeters and producing a conspicuous mass of pitch and frass on the outside of the twig. *D. rossi* Munroe, *D. auranticella* (Grote), and *D. abietivorella* (Grote) commonly infest ponderosa pine cones.

Pine webworms, genus *Tetralopha*, have recently been collected from ponderosa pines in the vicinity of Fort Collins, Colo. Their presence is conspicuous in late summer because of brown, frass-filled silk tents made by groups of feeding larvae. These tents occur throughout the crown at branch ends. Pupation is in the soil, with adult moths apparently emerging the following early summer to lay eggs. Webworm damage is not serious.



Figure 17.—Adult *Dioryctria* moth, wing span about 25 mm.

Leafroller Moths—Family Tortricidae

Four genera of tortricid moths are commonly found infesting ponderosa pines. Among them are several potentially serious pests of regeneration, stands being managed for high-value forest products, and/or high-value individual trees growing as ornamentals in urban situations.

***Rhyacionia* spp.**—Several species of *Rhyacionia* pine tip moths are known from ponderosa pine. These include the southwestern pine tip moth, *R. neomexicana* (Dyar), the western pine tip moth, *R. bushnelli* Busck, and *R. fumosana* Powell. All the pine tip moths infest new shoots, hollowing them out. Severe tree stunting is possible, but mortality is rare. *R. neomexicana* is a serious pest of some forest plantings and natural regeneration in Arizona, and can also be important in windbreak and Christmas tree plantings throughout the area. Fortunately, once trees grow beyond 3-4 m tall, they are no longer attacked severely. On smaller trees, though, damage can be serious.

***Petrova*.**—One species, *P. metallica* (Busck), is commonly found. These “pitch nodule moths” mine in new shoots and produce a consolidated mass of pitch at the site of entry into the shoot, like *Dioryctria cambiicola* and *D. baumhoferi*. As in the case of *Dioryctria*, the portion of the shoot beyond the pitch nodule dies, and stunting and deformation result.

***Eucosma*.**—Larvae of the western pine-shoot borer, *E. sonomana* Kearfott, are responsible for reduced height growth of ponderosa pine in certain locations. The larvae infest new terminals, but feed only in the pith; the terminal often lives, but is stunted. Laterals assume dominance; or the leader retains dominance, but is short. A characteristic “shaving brush” appearance results as shoot length is reduced and needle bundles are more closely spaced than usual. After a short feeding period, the larvae abandon the aerial portion of the tree to overwinter in silken cocoons in the soil.

***Cydia* (= *Laspeyresia*).**—This genus includes several species of “seed moths.” Distribution and relative abundance of the insects are largely unknown, as is their impact on ponderosa pine seed production.

Pine tortrix, *Choristoneura lambertiana ponderosana*

Obraztsov.— This moth, a close relative of the well-known spruce budworm, is common in certain ponderosa pine areas in some years. Heavy defoliation has tended to be localized in canyons and along highways, rather than being extensive, and the tortrix is not considered a major pest. Larvae feed on new needles and can cause total loss of the current year's foliage. They chew through the needle sheath and feed on the succulent new needle tissue inside. Abundant unconsolidated webbing is produced. Damaged needles fade rapidly and most drop by winter. The insects pupate in the tips near the feeding sites. Eggs are laid in overlapping rows on the older needles, and the tiny larvae overwinter in silken hibernacula in protected locations on the tree.

Gelechiid Moths—Family Gelechiidae

This family includes a group of moths known as needle miners (fig. 18), some of which are found in pine forests. One species, the ponderosa pine needle miner, *Coleotechnites ponderosae* Hodges and Stevens, has since 1971 been recognized as a pest in certain parts of the Colorado Front Range, as well as in the Black Forest, Durango, and other Colorado areas. The insect has a 1-year life cycle, with the adults flying in August and September. Eggs hatch in mid-to-late September, and the insects overwinter inside needles in the larval stage. *C. ponderosae* prefers older foliage, and relatively few of the new, high nutrient-producing needles are damaged. Nevertheless, heavy feeding over several successive years can result in weakened trees.

Another ponderosa pine needle miner, an undescribed species of the genus *Exoteleia*, has recently been identified from west-central New Mexico and east-central Arizona. This species, while closely resembling and closely related to *C. ponderosae*, has a slightly different life cycle. It appears to prefer new foliage, and has more potential for adversely affecting host trees.



Figure 18.—Needle miner life stages, entrance and exit holes in needle, and larvae inside needles. Moth wing span about 12 mm.

Ermine Moths—Family Yponomeutidae

One species of ermine moth, *Zelleria haimbachi* Busck, is relatively common in ponderosa pine. *Z. haimbachi*, the pine needle sheath miner, feeds in the latter larval stages much like the pine tortrix, and defoliation caused by the two is superficially hard to separate, especially when they occur together, as they often do. Both pupate in masses of silk in the mined shoots; however, *Z. haimbachi* larvae overwinter within pine needles while those of the pine tortrix overwinter within hibernacula in bark crevices.

Flies and Midges—Order Diptera

A few species of Diptera, mainly in the family Cecidomyiidae, cause damage to ponderosa pine. Attacks by the gall midge *Conararia coloradensis* Felt causes excessive tissue growth of the fascicles and needle base and reduced length of the needles. Galled needles (fig. 19) are globular, 6-12 mm in diameter and very short; some are so deformed as to be nearly unrecognizable. Infested needles drop from the tree at the end of the first year and thus attacks can result in conspicuous loss of foliage. Fortunately, heavy infestations seem to be highly localized, and the insects are not serious pests.

Cone midges are also found in ponderosa pine, but little is known about their habits or the damage that they cause. Larvae of *Rubsaamenia keeni* Foote are very small (3 mm) red, pink, or orange maggots found within and around cone scales and seeds. The adults are tiny, fragile flies.

Pine resin midges, also called pitch midges, are similar in appearance to cone midges but are more damaging. For example, *Cecidomyia piniinopis* Osten Sacken attacks current year's shoots of ponderosa pine, often deforming and sometimes killing them. The damaged shoots fade, droop, and eventually die. Infested tips have small, resinous pockets containing small, red maggots under the bark. If the larvae are not numerous, the tips may recover, but growth is reduced. Populations can vary greatly from year to year due to natural control factors.

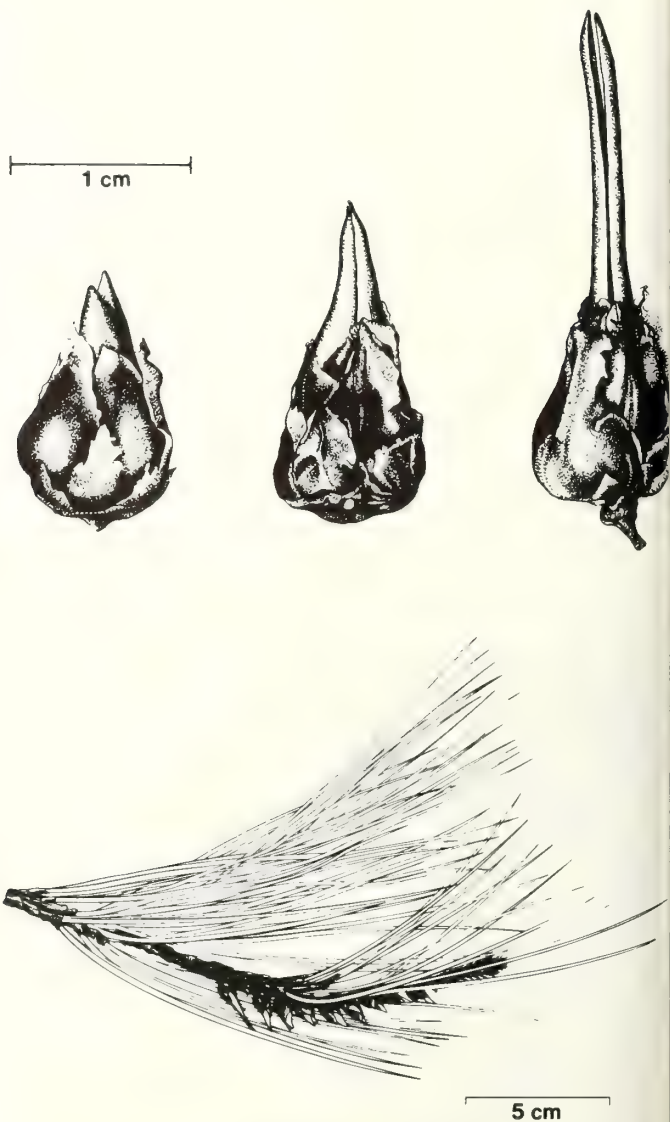


Figure 19.—Galls in ponderosa pine due to infestation by gall midges (a) shows variability; (b) shows galls in place on shoot.

Ants, Bees, Sawflies, and others—Order Hymenoptera

Conifer Sawflies—Family Diprionidae

Neodiprion fulviceps (Cresson), *N. gilletti* (Rohwer), *N. venralis* Ross, *N. weneri* Ross, and *Zadiprion townsendi* (Cockerell) are among species known from the area. In general, sawflies are not serious pests in the central Rocky Mountains and the Southwest. The name “sawfly” refers to the saw-like ovipositor with which females make the slits in pine needles where they deposit their eggs. Larvae of these sawflies feed on the foliage and drop to the soil to pupate in hard, capsule-like cocoons. Like many other defoliators, they may also feed on the exterior surfaces of young tender shoots. Young sawfly larvae feed in clusters on individual needles (fig. 20). No webbing is produced. The larvae have shiny heads and a distinctive habit of rearing back from their feeding position when disturbed. Each species overwinters in one of three life stages: egg, larva, or pupa. Most overwinter as eggs or pupae, but *Z. townsendi* overwinters on the foliage in the larval stage.



Figure 20.—Young sawfly larvae, about 18 mm long, clustered characteristically on pine needles.

Horntail Wasps—Family Siricidae

Horntail wasp larvae occupy ecological niches similar to those of the wood-boring beetles, Buprestidae and Cerambycidae. They tunnel in the sapwood of damaged, dying, or recently killed trees, including ones killed by forest fires. *Sirex*, *Xeris*, and *Urocerus* are common genera. The name "horntail" refers to the dangerous-looking ovipositor on the adult female and also to a posterior projection on the larvae.

Webspinning Sawflies—Family Pamphiliidae

The genus *Acantholyda* contains at least two species (*A. verticalis* (Cresson) and *A. brunnicans* (Norton)) known from area ponderosa pine. Larvae of *A. verticalis* feed solitarily on new growth and often shroud the terminal bud area with webbing and frass pellets. Mature larvae are large for sawflies with longitudinal striping. Pupation is apparently in the soil. The adults are also large (> 20 mm).

Ants—Family Formicidae

Ants are commonly found in and around pine trees. They have no direct effect on living trees, but presence of ants often indicates the presence of aphids, from which the ants obtain honeydew. In some cases, protection afforded aphids by ants may favor aphid population increases. Several species of ants commonly obtain nectar from ponderosa pine dwarf mistletoe and, in the process, pollinate dwarf mistletoe flowers. Carpenter ants, large black species, often tunnel extensively in down and decaying wood and sometimes colonize unfinished wood in cabins and other structures.

**Braconids, Chalcids, and Ichneumons—Families
Braconidae, Chalcididae, and Ichneumonidae**

Many insect species in these families are parasites of other—sometimes harmful—insects (fig. 21). One genus of chalcids, *Megastigmus*, includes several species that colonize conifer seeds and can be pests. *M. albifrons* Walker occurs throughout the West.

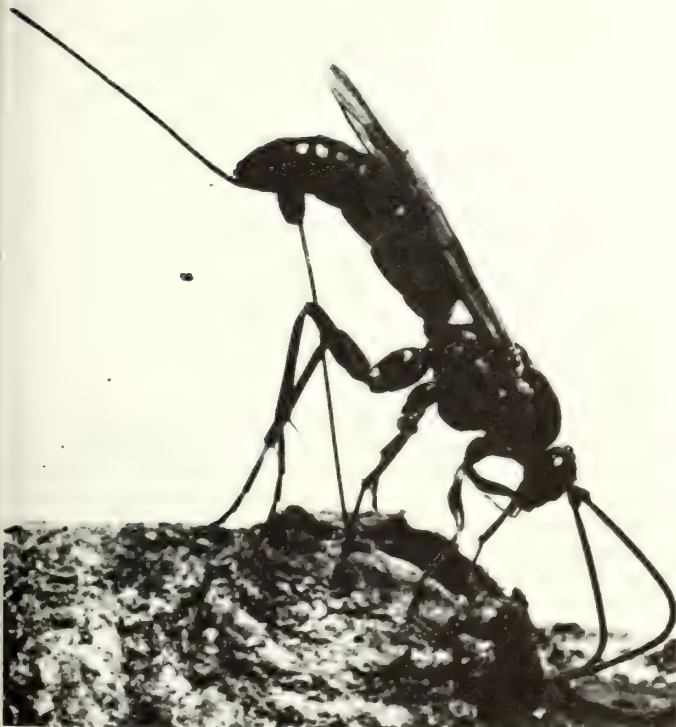


Figure 21.—Parasitic wasp, *Glypta* sp., laying egg in body of concealed host larva. Wasp is about 10 mm long.

SECTION 4

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SECTION 5

GLOSSARY

- Antennae** (sing. antenna): The pair of jointed sensory appendages on the insect head, commonly called feelers.
- Beak**: The protruding mouthparts of certain kinds of insects (e.g., aphids and cicadas) through which the insect feeds.
- Beating**: A method of collecting insects in which foliage or branches are beaten over a cloth onto which the insects drop.
- Blue stain**: Discoloration in wood caused by fungi, usually genus *Ceratocystis*, which are carried by bark beetles.
- Cambium**: In a tree, the growing part between the inner bark and the wood. **Cambial**: Pertaining to the area of the cambium.
- Chambial**: Pertaining to the area of cambium.
- Chalcid**: A small (1- to 3-mm long), heavy-bodied wasp belonging to the family Chalcididae.
- Cone**: The female reproductive structure of a conifer; the part that bears the seeds.
- Cone scales**: The woody (in pines) individual elements of a cone attached to the central core.
- Conifer**: A member of the group of cone-bearing trees; trees that generally have persistent needles.
- Crown**: The part of the tree having branches and foliage; the upper part.
- Declivity**: In bark beetles, the sloping upper rear portion of the abdomen.
- Defoliator**: An insect that chews foliage from trees.
- Dominance**: In conifers, the tendency of the topmost shoot to remain the tallest as the tree grows.
- Dwarf mistletoe**: A fleshy parasitic plant that grows on conifers.
- Fading**: Yellowing or otherwise abnormal discoloration of foliage, often resulting from insect activity.
- Fascicle**: In conifers, particularly pines, an individual bundle of needles.
- Flag**: To fade.
- Flagging**: A conspicuous clump of fading foliage; dead needles, usually on the ends of branches.
- Frass**: The mixture of feces and sawdust left behind by many chewing insects.
- Gall**: An abnormal growth of plant tissues, normally stimulated by some outside factor, often insects or mites.
- Gallery**: A series of chambers and/or tunnels in which insects, particularly bark and ambrosia beetles, live. Each species has its particular kind of gallery, and can often be identified by it.

- Habitat:** the place where an insect lives.
- Hibernaculum** (pl. hibernacula): A tiny shelter constructed of silk or some other material in which an insect (usually a larva) overwinters or hibernates.
- Honeydew:** A sugary excretion produced by aphids and other sucking insects.
- Host:** The plant (or animal) on which an insect feeds.
- Lateral:** On a pine tree—a more or less horizontal limb or branch, as opposed to the leader, or topmost tip of the tree.
- Maggot:** Legless, worm-like fly larva (Diptera).
- Nidge:** A small, fragile fly, often resembling a mosquito.
- Mine:** To bore or dig beneath the surface (e.g., the activity of certain kinds of insects); also the hollowed-out area resulting from mining.
- Needle sheath:** On pines, the fibrous wrapping of the needle bundle that helps hold the bases of the needles together.
- Niche:** What the insect does; the role it plays in the environment.
- Overwinter:** In the case of insects, to pass the winter, often in an inactive developmental stage.
- Oviposit:** To lay eggs.
- Ovipositor:** In female insects, the structure with which the eggs are placed.
- Pith:** In twigs of trees and shrubs, the more porous, central part.
- Population dynamics:** How populations change in number of individuals from generation to generation.
- Predator:** An organism that feeds, usually externally, on another.
- Regeneration:** In forestry, this generally refers to young seedling or sapling trees.
- Root collar:** The part of the stem of a tree just below the surface of the ground.
- Scale, scale insect:** One of a group of sucking insects that become fixed at feeding locations, covering themselves individually with a more or less hard, protective coating.
- Slash:** Branches, treetops; generally parts of trees left in the woods after logging.
- Stage:** In insects, any of the development periods (e.g., larval stage).
- Terminal** (syn. leader): The topmost shoot of the main stem of a tree.

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Stevens, Robert E., J. Wayne Brewer, and David A. Leatherman. 1982. Insects associated with ponderosa pine in the Rocky Mountains and the Southwest. USDA Forest Service General Technical Report RM-94, 44 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Ponderosa pine serves as a host for a wide variety of insects. Many of these, including all the particularly destructive ones in the area, are discussed in this booklet. Included are a key to the major insect groups, an annotated list of the major groups, a glossary, and a list of references. This report supersedes USDA Forest Service General Technical Report RM-75.

Keywords: *Pinus ponderosa*



Rocky
Mountains



Southwest



Great
Plains

U.S. Department of Agriculture
Forest Service

Rocky Mountain Forest and Range Experiment Station

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Research programs at the Rocky Mountain Station are coordinated with area universities and with other institutions. Many studies are conducted on a cooperative basis to accelerate solutions to problems involving range, water, wildlife and fish habitat, human and community development, timber, recreation, protection, and multiresource evaluation.

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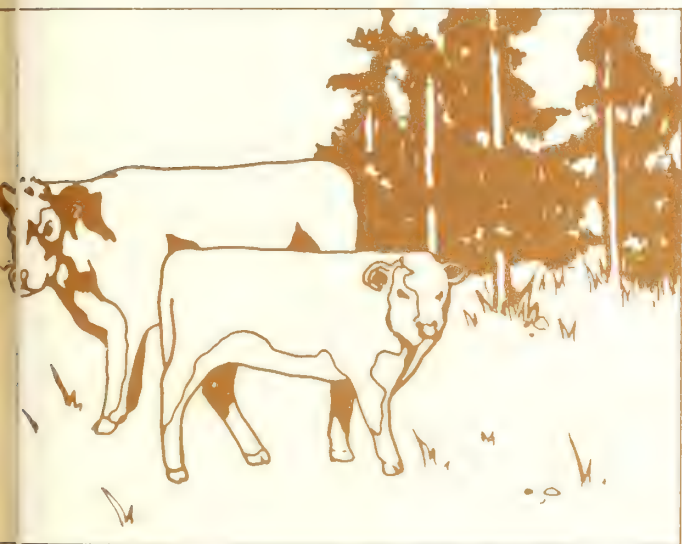
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Monetary Valuation of Timber, Forage, and Water Yields from Public Forest Lands

Thomas C. Brown



General Technical Report RM-95
Rocky Mountain Forest and
Range Experiment Station
Forest Service
U.S. Department of Agriculture

Abstract

This paper describes methods for deriving monetary values for three market products of the forest: timber, forage, and water. Elements of the theory are reviewed and applied to actual forest conditions in central Arizona using available data. The paper should aid analysts with microeconomics training in understanding economic studies of resource values and in conducting valuations during the public land management planning process.

Acknowledgement

Pramila Poudel, formerly with the Rocky Mountain Forest and Range Experiment Station, worked on an early version of this paper.

Monetary Valuation of Timber, Forage, and Water Yields from Public Forest Lands

**Thomas C. Brown,
Rocky Mountain Forest and Range Experiment Station¹**

¹*Headquarters is in Fort Collins in cooperation with Colorado State University.*

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Monetary Valuation of Timber, Forage, and Water Yields from Public Forest Lands

Thomas C. Brown

INTRODUCTION: THE RESOURCE ALLOCATION PROBLEM

Forests contribute in numerous ways to human satisfaction. They may provide timber, water, livestock forage, wildlife habitats, recreation opportunities, wilderness, or any combination of these. They also provide services such as the conversion of carbon dioxide to oxygen, the binding of soil, and the regulation of climate. However, any given forest site can only produce one combination of these goods and services at a time. Choice of one combination, or management alternative, requires giving up other alternatives. Thus, forest managers face an allocation problem.

Land management planning (e.g., forest planning) in a multiple use setting is a very complex allocation problem, particularly for public land producing a great variety of products. Land must be allocated to different uses and funds to different management activities. Public land management decisions are typically based on, among other things, a combination of efficiency and equity considerations. An efficient allocation of resources is one which maximizes the net benefit to society, regardless of who gains and who pays. Efficiency is improved if the value of the economy's output is increased for a given amount of resource input. An equitable allocation is based on someone's opinion of who should benefit and who should pay (see Haveman and Weisbrod 1975).

Estimates of the relative importance of the effects of management alternatives are crucial in comparing the efficiency of the alternatives (see Brown 1981). Monetary values, the estimates of importance used in economic analysis, are one source of importance estimates for land management planning.

Under the existing institutional framework some forest products, such as recreation, environmental, and esthetic goods and services, do not generally move through markets and, therefore, do not have market-determined values. Other products, such as sawtimber and pulpwood stumpage, forage, and water runoff, move through the market, although sometimes in an indirect and limited sense. For example, the Forest Service sells stumpage, but often not in a competitive market. The right to use forage for livestock on public land is also sold, but the price is usually determined administratively. Public agencies rarely charge for the water, and downstream users are usually charged prices determined administratively by local governments or water companies. These are commonly called market products or commodities.

This paper is divided into two parts. The objective of Part I is to review what monetary values are and explain how monetary values for stumpage, forage for livestock, and water for downstream use can be de-

rived for use in comparing management alternatives for public land. The objective of Part II is to demonstrate the use of the methods, using central Arizona's stumpage, forage, and water market situation as an example. The paper does not cover how to use monetary values (for instance, in cost-benefit analysis) and only briefly mentions, in Part I, the basic assumptions and theoretical problems underlying the derivation and use of monetary values.

Part I is written for resource managers and analysts with a minimum of training in microeconomic theory, such as one should receive in a standard undergraduate intermediate microeconomics course. It assumes an understanding of such concepts as economic efficiency, competition, marginal cost and marginal revenue, opportunity cost, supply, demand, and externality. Part I is designed to provide readers with sufficient knowledge to understand Part II and, indeed, to attempt similar valuations of their own. Those familiar with the theory may want to proceed directly to Part II.

PART I: THEORETICAL CONSIDERATIONS

BACKGROUND

Money has the unique quality of being the medium of exchange for a great many goods and services, both factors of production and final consumer products. There is no other single scale in our society on which people, by their actions, record the importance they place on a large number of the goods and services. For this reason, monetary values are a convenient source of information about the importance of forest products.

The use of monetary values as measures of social value has its theoretical foundation in the welfare economics notions of efficiency and Pareto optimality (see Baumol 1977, Bator 1957, Graaff 1957, Ferguson 1972, Sassone and Schaffer 1978). Operationally, a purely competitive economy assures an "efficient" (Pareto optimal) allocation of resources. According to standard economic welfare theory, in a purely competitive economy, the profit-seeking activities of producers result, as though guided by an "invisible hand," in an allocation of resources which maximizes the aggregate satisfactions of consumers. A competitive economy tends to equate the price of a good or service with its minimum average cost, indicating that competitive firms use the most efficient technology available to them and charge the lowest price consistent with their production costs. The competitive price system will reallocate resources in response to a change in consumer tastes, technology, or resource supplies so as to maintain allocative efficiency over time.

The competitive paradigm is used throughout this paper. The methods described herein all utilize competitive markets because such markets provide the most appropriate estimates of monetary values for public decision making. It should be mentioned that there are potential reservations with the use of such methods to derive estimates of social value. These concerns fall in three groups, ranging from the purely theoretical to the practical. The first group consists of the basic assumptions of welfare economics. Among these are that individual tastes, or wants, are taken as given and not questioned (this reflects the utilitarian philosophical basis of welfare economics) and that, for all practical purposes, the existing income distribution is accepted as given and proper (see Krutilla 1961, Samuels 1972). The second group of concerns consists of impediments to a purely competitive economy, which render any market measures of value theoretically impure. These include noncompetitive (e.g., monopolistic) markets, market disequilibrium, externalities, and the fact that not all goods (e.g., public goods) are sold in the market place (see any basic microeconomic text, such as Hirshleifer 1980 or Ferguson 1972). The third group consists of the lack of adequate data to employ the methods. The third group will be discussed in the course of explaining and demonstrating use of the methods.

These reservations are mentioned not to disillusion the reader, but rather to place the main body of the paper in a realistic setting. For discussion of the first two groups of concerns the reader is directed to other sources, of which there are many, in the welfare and environmental economics literature, including those cited above.

What Are Monetary Values?

This section contains a brief review of some elementary microeconomic principles. The value of something (a certain amount of some kind of good or service, called a product) to an individual depends on many things—the individual's tastes or preferences, the use to which it is to be put, the amount of the good or service already in the possession of the individual, its quality, and the availability of substitutes, to name a few. The individual's willingness to pay for successive units of a product at any given time depends on such determinants, plus his or her budget constraint. Willingness to pay is a constrained (by income) measure of the value, expressed in monetary terms, of a given product relative to all other products.

An ordinary demand schedule, or curve, for a product represents quantities which are or would be purchased at various prices during some time period, given constant incomes, preferences, and prices of other products. With rare exceptions, the demand schedule is downward sloping, representing the diminishing marginal utility of the product. For example, the demand schedule in figure 1 shows the amounts of apples which an individual would purchase at given

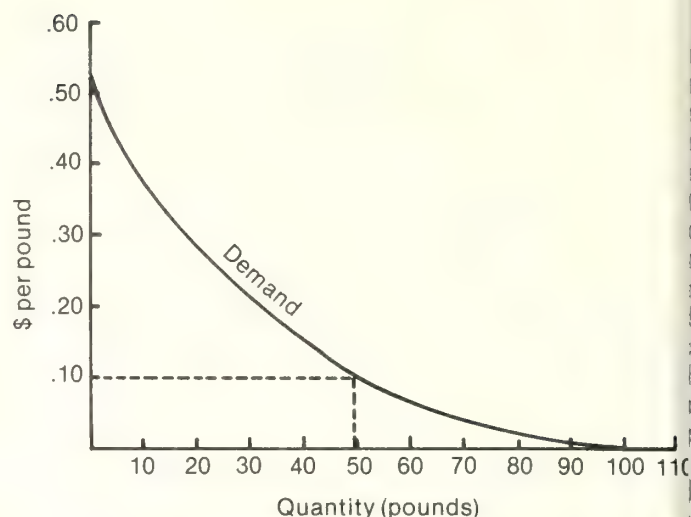


Figure 1.—An individual's demand curve for apples in 1979.

prices. At \$0.30 per pound, 20 pounds would be purchased, and at \$0.10 per pound, 50 pounds would be purchased. Note, however, that even if apples were free, only 100 pounds would be taken. Also note the marginal nature of the demand schedule: The initial pound of apples has a value to the individual of about \$0.53, and each additional pound has a slightly lower value. For example, having 49 pounds, the individual's willingness to pay for the 50th is \$0.10. Thus the individual's demand schedule depicts a series of willingnesses to pay values corresponding to a series of quantities.

The horizontal summation of the individual demand curves for the product in a given location is the aggregate, or market, demand curve.² For example, the demand curve for apples in some city may be as in figure 2.

Corresponding to the demand curve is a supply curve representing the marginal cost of producing additional quantities of the product and, therefore, the quantities which rationally will be supplied at given prices. The horizontal summation of the firms' supply curves gives the market supply curve. The supply curve is shown to intersect the demand curve at 24,000 pounds in figure 2. The intersection signifies the market price, which is \$0.20 per pound in figure 2. Price is the willingness to pay "at the margin," where demand equals supply, and is sometimes called the value in exchange. It is the result of the collective actions of all buyers and sellers who participate in the market economy. The total gross value for the consumers of the 24,000 pounds is given by the area under the demand curve from 0 to 24,000 pounds (about \$9,000) and the total cost of supplying the apples is given by the area under the supply curve from 0 to 24,000 pounds (about \$3,600).

When 24,000 pounds are bought and sold at \$0.20 per pound, a total of \$4,800 will change hands, represented by the rectangle enclosed by the dotted

²For public goods, where one person's consumption does not diminish another's, as with radio waves, a vertical summation is required.

ines in figure 2. However, consumers derive greater than \$4,800 of value. The additional value, represented by the upper shaded area in figure 2 (about \$4,200), is the consumers' net value and is called the consumers' surplus.³ The consumers' surplus exists because all but the last apple exchanged has a value greater than the marginal value. Producers will also benefit from the apple transactions. While \$4,800 changes hands, only a portion of that sum was necessary to cover the producers' costs. The residual or producers' net value, called the producers' surplus, is represented by the lower-shaded area in figure 2 (about \$1,200). The total net value or surplus is the sum of the consumers' and producers' surpluses (\$4,200 + \$1,200 = \$5,400).

The average gross value of apples to the city's residents is calculated as the total area under the demand curve to the left of the equilibrium point divided by the total quantity consumed ($\$9,000 \div 24,000$), or about \$0.38. The average net value accounts for supply cost, and is $(\$9,000 - 3,600) \div 24,000$, or about \$0.23. This is considerably higher than the exchange value of \$0.20.

Thus, there is more than one monetary value for a given product in a given location. For our example, there are five total values, a gross expenditure of \$4,800, a gross value of \$9,000, a consumers' surplus of \$4,200, a producers' surplus of \$1,200, and a net or combined surplus value of \$5,400; and several unit values, including a marginal value (price) of \$0.20, an average gross value of \$0.38, and an average net value of \$0.23. In addition, there are the willingness to pay values of each individual for each quantity of the product.

From the efficiency standpoint, combined surplus (consumers' surplus plus producers' surplus, and hereafter just "surplus") is the appropriate measure of the

total monetary value of a product in a given market. Surplus is the appropriate measure for two reasons. First, it gives equal weight to both consumers' benefits and producers' benefits. Second, it is a net value. That is, it is the value to consumers and producers after their respective costs (of purchase for consumers and of production for producers) have been covered, and thus avoids any double counting.

Price is perhaps the most commonly cited example of a monetary value. In fact, "value" is often used in place of price in economics literature. Price is not simply a transformation of a total value, as are the average values. Rather, price focuses on the margin. It is the change in the total gross value with a one unit change in output or, in slightly different terms, the marginal gross value. It is a gross rather than net value because it does not account for production cost. If the price in a market is determined by the intersection of demand and supply (if the market is in equilibrium), there is no surplus (net value) associated with the one unit change. However for markets not in equilibrium, or where supply changes, price is sometimes a very useful base from which to calculate changes in surplus.

Which Monetary Values Are Useful in Public Land Management Planning?

As stated in the previous section, surplus is the correct monetary measure of total value from the efficiency standpoint. If the efficiency effects of alternatives are required as part of a land management planning exercise, measures of surplus are appropriate. However, measures of total surplus are generally unobtainable and often unnecessary for land management planning.

Measures of total surplus are unobtainable because they require demand and supply schedules for all output quantities up to the equilibrium quantity. Such complete schedules are not observable and very difficult to estimate. However, measures of total surplus are unnecessary for land management planning whenever the alternatives under consideration cause only changes in the quantity or quality of products of the land under management. In fact, in most instances, rather small changes in forest product output are being considered. In such cases, the changes in surplus associated with the changes in product output can often be measured directly.

The base from which changes in the quantity and quality of products of the land under management are measured is the "without" alternative. This alternative represents the conditions that are expected to exist in the future if current management direction continues unchanged. The "without" alternative is the "without" situation in the "with and without" framework suggested for use in evaluating water resource projects (U.S. Senate 1962, U.S. Water Resources Council 1973 and 1979) and in evaluating national forest management alternatives (see the Forest Service Manual 1970.8, 1981).

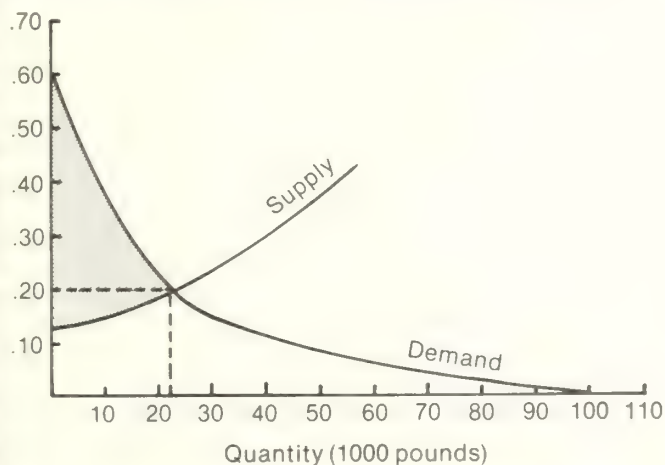


Figure 2.—Hypothetical market demand and supply curves for apples in 1979.

³The ordinary demand curve is theoretically incorrect for determining consumers' surplus. The compensated demand curve, which adjusts for the real income changes associated with changes in price, gives the correct surplus measure. However, the compensated demand curve is not observable empirically. Luckily the ordinary demand curve gives a good approximation of the true surplus for most cases (Freeman 1979). The error in using the ordinary demand curve, in any case, is usually minor in light of all other errors in estimating monetary values.

The value of a change in output of a forest product under an alternative other than the "without" alternative is represented by the change in consumers' surplus plus the change in producers' surplus. The total monetary measures and their averages, described above in terms of the apple market, have no role in directly measuring changes in surplus. In appropriate circumstances, however, price plays a major role, especially if it does not change with the change in output. When the price does not change with a change in the output of a forest product, the entire surplus change accrues as a change in producers' surplus, and price in appropriate circumstances is the base from which that change is calculated. When the price changes with a change in the output of a forest product, part or all of the surplus change accrues as consumers' surplus; nevertheless, price can sometimes be used as the base in approximating the surplus change.

When Is Market Price an Appropriate Marginal Value?

Although our economy does not match the purely competitive ideal which assures an economically efficient allocation of resources, many market situations in the economy provide appropriate prices or allow derivation of appropriate prices. "Appropriate" is used in the sense that the prices are estimates of marginal gross value useful in estimating changes in surplus resulting from changes in product output.

While some of these useful market situations include noncompetitive markets (e.g., monopolies), most require competitive markets. The essence of a competitive market is that individual buyers and sellers have no control over product price. A market is considered purely competitive if it has (1) a large number of buyers and sellers (if there are many buyers and sellers acting independently, no one buyer or seller can affect product price by varying the quantity bought or sold); (2) free entry (anyone who wishes to enter or quit the industry must be free to do so); (3) product homogeneity (all units of the product must be very similar—beef is a relatively homogeneous product; perfume is not); and (4) perfect knowledge (all buyers and sellers should be aware of what other buyers and sellers are doing).

The degree to which these conditions are met determines the competitiveness of the market. In the United States, the full range of possibilities exists, from the (nearly) purely competitive such as the lumber, beef, and feed grain markets, to the monopolistic, such as most water and electric power markets.

A product's price is appropriate if the product is sold competitively without market interference; and, in the situation where the product is an input in the production of some secondary product(s), if all such secondary products are also exchanged in competitive markets without interference. We will dissect this sentence by considering the following: (1) what is meant by "sold competitively," (2) what is meant by "without market interference," (3) what happens when

the primary product is sold competitively but the secondary product is not, and (4) derivation of an appropriate price when the primary product is not sold competitively but the secondary product is.

If a product is exchanged in a competitive market there are many sellers and many buyers, as described above. A product "sold competitively" is sold in a market where the buyers' side approaches the competitive market model. Of particular importance is that all buyers are price takers—they have no power to influence the price of the product. However, the seller does not have to be a competitor, and in fact can be a monopolist. For example, if the product is sold to consumers, the price of the product represents the consumers' marginal willingness to pay for the product regardless of whether the seller's side consists of many or only one seller, as long as the product is sold to consumers without market interference. Even if the seller is a monopolist, who restricts production below the level which would be obtained if the product were exchanged in a competitive market, and charges a correspondingly higher price for the product than would be reached in a competitive market, the price still represents the marginal willingness to pay of the consumers in the market. Consumers would be willing to pay that price for a small increase in output of the product. If a public policy somehow caused a unit increase in output of the product, the existing (pre-change) price would represent the gross monetary value of the change.

"Market interference" in the previous two paragraphs refers to either government price controls which interfere with the natural forces of the market, or administrative decisions on the part of the seller(s) to not maximize profits. For details on the impact of price controls on appropriate price, see Sassone and Schaffer (1978), chapter 5. The effects of sellers' non-profit maximizing goals are difficult to adjust for, even when they can be detected.

When a product is sold competitively without market interference to secondary producers who do not sell their products in competitive markets, the price of the input is inappropriate for valuing a change in its availability, provided the change in input would cause a change in output of the noncompetitive secondary producers. For example, assume a monopolist (that is, on the seller's side) buys the input in question at its competitive price. The appropriate price, or gross unit value, of the input in the production of the monopolist's output is greater than its competitive market price. This is because the input has additional value tied up in the final product. This additional value is reaped as monopoly profit. The appropriate price of the input for this use could only be derived from the price of the final product. Such a derivation is complicated, however, when there are other inputs involved in the production of the monopolist's product, for there is no unequivocally correct way to allocate the monopoly profit among the various inputs. Derivation is further complicated if the product produced from the input is itself an input in the production of a product not exchanged in a competitive market.

If a product is not sold competitively, its price is inappropriate for estimating changes in surplus, unless it by chance approximates the competitive price. A product is not sold competitively if the buyers are so few that they individually, or through collective action, influence the price; or, in the case of products from public land, if the product is sold at an administered price. The competitiveness of purchasers of public timber varies considerably with location. In some situations, there may be only one bidder, who purchases the timber at an appraised price. The purchasers of public forage are usually determined by long-term lease agreements; the grazing fees are administered prices. Water is seldom sold competitively, and usually sold at administered prices. It is often very difficult to determine how close an administered price is to the competitive price.

The appropriate price of a noncompetitively sold input can be derived from the end product price if the end product is a consumer good exchanged in a competitive market without market interference and if all other inputs are sold competitively. It can also be derived from end product price if the end product is itself an input in production as long as the subsequent end products are also exchanged in competitive markets.

METHODS FOR MONETARY VALUATION OF TIMBER, FORAGE, AND WATER

Because of lack of competitive markets and lack of data it is often impossible to assign forest products precise monetary values. Reasonable approximations, however, are generally obtainable without great expense for so-called market products such as timber, forage, and water. This section explains procedures for estimating the value of changes in outputs of those products.

Uncertainty about the effect of numerous necessary assumptions on resultant monetary values naturally gives rise to a range of possible values for any particular situation. Such a range makes sensitivity analysis necessary. In a sensitivity analysis, the relative position of alternatives using the best guess of the value is compared with the relative positions of the alternatives using other possibilities along the range for the value. In many cases, results of a comparison of alternatives will not be significantly affected by varying the value in question within its range. In other cases, where sensitivity analysis shows that the results are sensitive to the value, effort may be necessary to estimate the value more accurately.

The discussion here deals only with cases where timber, forage, and water are beneficial forest products. Thus, increases in output or improvements in quality of the products are beneficial changes, and decreases or impairments are adverse changes. This might not always be the case. For example, increases in runoff might cause flooding. Furthermore, the methods will be described in terms of beneficial changes in these three products. However, the methods

and underlying theory apply equally well to beneficial and adverse changes.

Timber, forage, and water have various uses. Timber is used in the production of various wood products, for fuel, as wildlife habitat, for recreation and enjoyment of scenery, for protection of soil from erosion, for production of oxygen, etc. Forage is consumed by livestock and some wildlife species, used to hold soil, adds to the beauty of forest scenes, etc. Water is used to sustain life, for recreation, as fish habitat, for irrigating crops, etc. This paper is about valuation of those uses which can be valued using market-determined prices. Commonly these uses are stumpage for timber, livestock production for forage, and power and downstream consumption for water. Valuation of timber, forage, and water for other uses may employ market price information, but also relies on the use of personal interviews of some sort, and generally requires extensive expertise in economics and statistics.

Step 1 in valuation is to determine whether the change in a forest product is one of quality or quantity or both. **Step 2** is to determine what use or uses of the forest product are affected by the change in quality and/or quantity in the given location. The value of the change depends on the use which is affected. For example, if timber growth increases in some location, will the increased growth be harvested? Or, if forage quality improves, will this improvement allow improved livestock production?

While it may seem elementary that the value of a change in output of a forest product is calculated only in terms of affected uses of the resource, this point is often missed when monetary values are applied to site-specific situations. For example, a small potential increase in pulpwood might be valued at the current pulpwood price. However, it may be that, because of a lack of production capacity, not all the pulpwood currently available for harvest is sold. Clearly an addition to the quantity currently available would have no value, except in the case where the increase was more accessible than some of the pulpwood which would have been harvested in the absence of the increase. In this case, the value would be equal to the harvest cost savings caused by harvesting more accessible pulpwood. Additional examples are the case where additional forage would not be used because of the lack of water developments, and the case where additional water would not be used because of the lack of storage facilities.

The value of an increase in runoff at points of use downstream is sometimes a cause for confusion because it is claimed that water has many downstream uses. Indeed, in many cases water is used for a full range of municipal, industrial, agricultural and recreational uses. The crucial question to be asked is, What use will be affected by the increase? In most cases, the higher-valued uses will have been able to bid water away from lower-valued uses, so that only the lowest-valued existing use (the marginal use) at a given time would use additional water. The value of water in this marginal use is equivalent to competitive market price.

Step 3 in valuation is to decide which forest product changes will be valued, and for which uses those products will be valued. **Step 4** is to choose an appropriate valuation method and apply it.

The available methods which rely on market-determined prices fall into two main groups—those used where the relevant market price is not affected by the change in output and those where the price is affected. The market price will not be significantly affected if the change in output level resulting from the change in quantity or quality of the forest product is small enough relative to the total quantity supplied in the affected market, or if output level is completely unaffected. The market price will be affected if the change in quantity supplied is large enough so that the product will only be purchased at lower prices.

Constant Product Price

The methods described here for valuing changes in timber, forage, or water are further distinguished by whether the forest product or a similar product is sold competitively or, if not, whether it is used in the production of another product which is exchanged in a competitive market and from which the value can be derived.

The Direct Observation of Market Transactions Method

Where the forest product is sold competitively to consumers, or to producers who in turn exchange their end products in competitive markets, where a quantity change is being valued, and where the change is a small enough percentage of the total quantity supplied so as to not affect market price, the market price is a good estimate of the gross unit value of the change. For example, consider figure 3. A horizontal demand curve (D) is used in figure 3 to show that market price is unaffected by changes in the output quantity of the producer in question (here the Ponderosa Forest). The demand curve for the entire industry would of course be downward sloping to the right, as in figure 2, as would the demand curve for an individual producer who represented a sufficiently large portion of the market. Thus the gross unit value of stumpage from the Ponderosa Forest (figure 3) is \$0.10 per board foot, regardless of output level.

The horizontal supply curve (S) in figure 3 shows that, at least for volumes from 4 to 7 MMBF per year, the Ponderosa Forest's marginal cost of supplying stumpage is \$0.06 per board foot. Current output is constrained at 5 MMBF per year (Q_1) by administrative decision, and continuation of this policy is the "without" alternative. An increase in output to 6 MMBF results in a net benefit (an increase in producer's surplus) of \$40,000 per year, represented by the shaded area. The net unit value of this increase is \$0.04 per board foot. Note that if the Ponderosa Forest were operating in equilibrium, with marginal cost equal to the stumpage price, there would be no net value to the increase. Note also that if the 5 MMBF per year constraint were not self-imposed, but rather a constraint over which the forest had no control, the supply curve would become vertical at 5 MMBF.

The value of a small increase in timber harvest in an area where buyers of stumpage compete freely for the stumpage could be determined in this manner. One merely needs to know the market price and the marginal cost associated with the change in output. A change in quality, under similar circumstances, could also be valued by observing the difference in existing market prices and costs for stumpage of the two qualities.

Where the forest product is not exchanged in a competitive market, as is often the case with public timber and nearly always the case with forage and water on public lands, the analyst may look for cases where the forest product is exchanged elsewhere in a competitive market. The success of this approach depends on how well the observed market resembles the market which would exist on the public land in question in the absence of institutional constraints. For example, timber stumpage of the same species may be exchanged in a competitive market in another area. Forage on private land is commonly sold for livestock grazing, and rates per animal unit month are reported by the USDA Economics, Statistics, and Cooperatives Service. Water is sometimes sold in markets with several buyers and sellers—the water rental market in the Denver-Fort Collins area is an example (Anderson 1961 and Maass and Anderson 1978).

Basing valuations on markets similar to the one for the resource in question requires great care, for two reasons. First, many market characteristics may be different, including the quality of the forest product, the demand schedule, and the supply schedule. Second, the observed private market may be so heavily influenced by the administered prices of the public forest resource that the market price is biased.

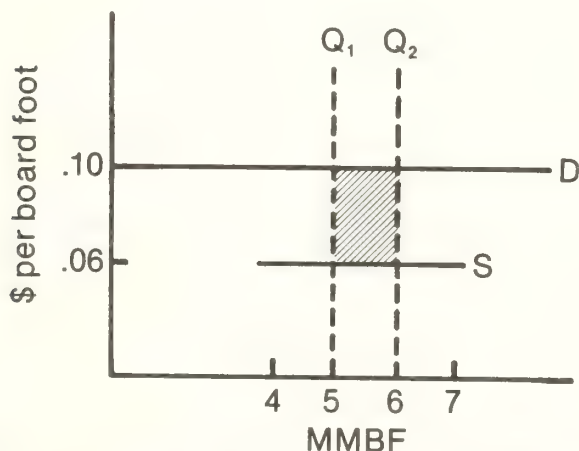


Figure 3.—Demand and supply schedules for ponderosa pine stumpage from the hypothetical ponderosa forest representing the benefit associated with an increase in output.

The Cost Savings Method

The cost savings method, and the change in net income which follows, apply where the forest resource being valued is an input in the production of some product, here called the "end product." The cost savings method applies where a change in the forest product input lowers the cost of production of the end product without affecting the level of output or the price of the end product. The cost savings calculated under such conditions is the gross monetary value of the change in the forest product input (the change in the secondary producers' surplus). The net value of the change is calculated by subtracting the costs to the forest of providing the change from the cost savings to the firms using the forest input.

The cost savings method applies only where the output level and price of the end product remain constant, because only then will the cost savings represent the full benefit. If output increased, additional benefits would accrue to the producers (assuming, again, a constant end product price), which would be measured as the net of revenue minus cost for the production increase. Of course, if the benefit from increased output were very small relative to the cost saving on the original output quality, the cost savings method would provide a low but approximate estimate of the benefit. And, if end product price dropped, with constant output level, consumers would benefit, the cost savings would decrease, and again the cost savings would not measure the full benefit. Note that as long as end product output level and price remain constant, it makes no difference what the price is, or whether the demand curve is horizontal or downward sloping (figure 4). It also makes no difference for use of the cost savings method whether the end product is exchanged competitively or not. Note also that this method could also be used to value the change in a forest product which increased production costs, provided the same conditions on end product output level and price were met.

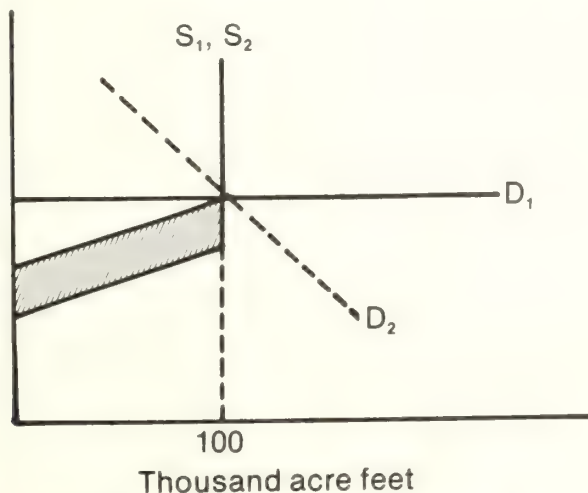


Figure 4.—Demand and supply schedules for municipal and industrial water representing a cost savings from improved quality of streamflow.

The rationale behind the cost savings method is that the cost saved represents inputs which could be used elsewhere in the economy. Using the inputs elsewhere improves the efficiency of resource use. If the cost of these inputs saved is determined competitively, the cost should represent the value to society of the saved inputs. Of course, the prices of the inputs for which the forest product is a substitute must remain constant. If their prices changed with the change in their use caused by the substitution, the cost savings would again not accurately measure the social value of the change in the forest resource.

The cost savings method is most commonly used to value changes in water. The method could be used to value a change in water quality where the change affected water treatment costs without affecting the quantity of water treated. For example, see figure 4, where S_1 and S_2 represent the marginal cost of providing water without and with the runoff quality improvement, respectively. The shaded area represents the cost savings with output constant at 100,000 acre feet.

The vertical portions of the supply curves in figure 4 represent very high costs of supplying more than 100,000 acre feet in either case, as might happen if more water could only be supplied by transporting water from another water basin through very costly canals and pumping stations. Costs are typically depicted by vertical supply curves if they are far too high to be reasonably considered. If the quantity constraint were purely administrative, however, and if marginal costs for quantities above 100,000 acre feet were simple extensions of costs up to that quantity, then the supply curves would be drawn to represent the gradually rising marginal cost past 100,000 acre feet, and the administrative quantity constraint would be represented by a vertical constraint line, as in figure 3. Note, however, that the shape of the supply curves past the fixed quantity is irrelevant for the application of the cost savings method because the method only applies if output is for some reason constrained at its "without" level.

The cost savings method could be used to value a change in quantity of water available for producing hydroelectric power, where additional hydroelectric power replaces more expensive power sources (see Young and Gray 1972 and Brown et al. 1974 for examples). It could also be applied to value a change in water quantity available for agricultural, municipal, or industrial uses, where the additional surface water replaces more expensive pumped water (see Brown et al. 1974 for an example) without affecting the total quantity.

An application of the cost savings method to timber would be to value the use of formerly wasted residues in producing power in a lumbermill where a more costly energy source is currently used. The benefit of the switch to residues is the cost savings. The analyst would, of course, have to account for conversion costs in calculating the cost savings. And, if the residues were formerly not wasted, but used for some other,

lower valued purpose, that value lost is a cost which must be subtracted from the cost savings.

The cost savings method might be used to calculate at least part of the value of forage in stabilizing soil. A cost savings of reduced erosion might be a reduction in the cost of downstream reservoir maintenance (dredging and/or reconstruction) (see Boster and Davis 1972 for an example).

The Change in Net Income Method

The change in net income method applies where the forest product is used in the production of a product which is exchanged in a relatively competitive market. The analyst measures the change in net income of firms which are affected by the change in a forest product input. For example, an increase in forage may allow affected ranchers to graze more cattle, yielding an increase in the ranchers' income. The change in net income of the affected firms is the gross monetary value of the change in input of the forest product or, in other words, the change in the secondary producers' surplus. The net value of the change (the net change in surplus) is calculated by subtracting from the gross value the costs to the forest of providing the change. Unlike the cost savings method, end product output is expected to change as a result of the change in the forest product,⁴ and the end product must be sold competitively.

The change in net income is calculated without including the monetary cost of the forest product input in question (the stumpage fee or grazing fee or water charge, if any). That is, the cost of the forest product input is not included in the set of costs subtracted from the producer's gross income to calculate the change in net income. Including this cost would interfere with the purpose of the exercise, to calculate the true monetary value of the input. Note, however, that in using the cost savings method, including the input cost does not affect the calculation of the cost savings unless that cost changes with the change in the input.

Three conditions, in addition to the end product being exchanged in a competitive market, must be met for use of the change in net income method. The first is that the producers' inputs, other than the one being valued, must be sold competitively. Only if this is true can the costs of those inputs be assumed to represent their real cost to society. The second condition is that the price of the end product must not change with the change in forest product quantity or quality. The change in net income is the full benefit if the affected firms capture the full benefit—that is, if the entire benefit is producers' surplus. This is only the case where the change in output which causes the change in firms' income does not affect the price of the end product. The third condition is that any products made from the end product (the product which uses the forest product as an input) must in turn be exchanged in competitive markets.

⁴Unlike the approach here, some authors categorize the cost savings method as a special case of the change in net income method.

The nature of the change in net income, and therefore its measurement, depends on the change in the forest product and the situation of the affected firms. There are at least three types of situations which would lead to a change in net income that is measurable using the change in net income method:

1. An increase in the quantity of a forest product which provides additional inputs to firms whose level of output was constrained by limited quantities of the input. The increase in quantity of the input supplied would allow increased production without changing the costs of producing the original (pre change) quantity of end product. For example assume that opening up a virgin area of the Ponderosa Forest for harvest provides stumpage for production of lumber over and above that available on a regular basis from traditional Ponderosa Forest harvest areas, and that the additional harvesting and milling by firms in the area does not affect their costs of harvesting and milling stumpage from traditional harvest areas. The additional stumpage would increase lumber producers' income as long as the additional costs were lower than the additional revenues. Assume that D in figure 5 is the demand curve for lumber of a given grade faced by the lumber firms which purchase stumpage from the Ponderosa Forest, and that S_1 is the supply curve of the firms representing their marginal costs of collectively supplying 5 MMBF of lumber net of stumpage cost. The vertical portions of the supply curves represent the high cost of transporting stumpage from other forests, which are too far away to be viable sources of supply. If harvest in the virgin area allows an additional 1 MMBF of lumber to be produced per year, a total of 6 MMBF would be produced. Because marginal cost is constant over the increase (depicted by the horizontal portion of supply curve S_2 for that range of output), the gross value of the increase in harvest (the change in net income) is simply the end product price (\$0.50) minus the marginal cost (\$0.40) times the increase in output (1 MMBF). If harvest in the virgin area allows an annual harvest of 8 MMBF per year (S_3), the change in net income is the entire shaded area in figure 5. The firms collectively will not produce more than 7 MMBF per year because that is the point where the cost of producing an additional unit of output just equals the return from the additional unit, in the short run. Of course, in the long run, firms could change their plants to produce more stumpage, or new plants could be built.
2. An improvement in the quality or quantity of a forest product input that reduces production costs, increasing the net income of producers through a cost savings on the original quantity of output and an increase in output. For example, an improvement in irrigation water quality could reduce irrigation costs (represented by the shift from S_1 to S_2 in figure 6) yielding a cost savings on the original output quantity (area $abde$), and allow increased output because of the drop in production costs, yielding additional

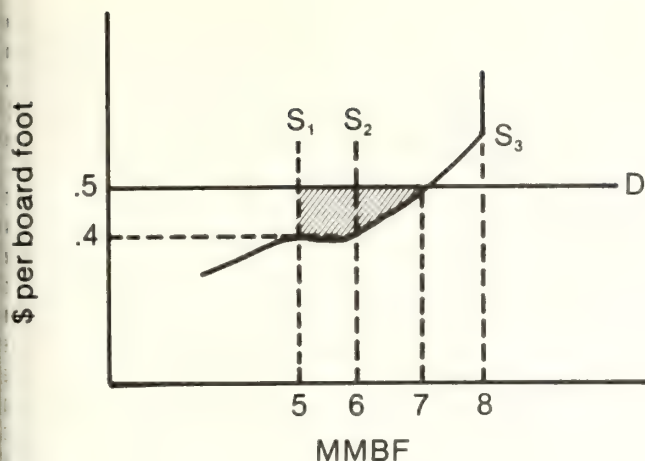


Figure 5.—Demand and supply schedules for ponderosa pine lumber from affected firms representing a change in net income with constant supply schedule.

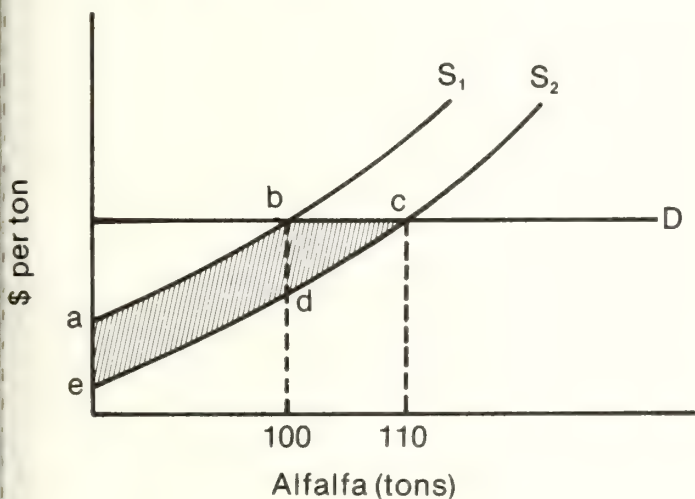


Figure 6.—Demand and supply schedules for affected farms representing a change in net income with a change in supply schedules.

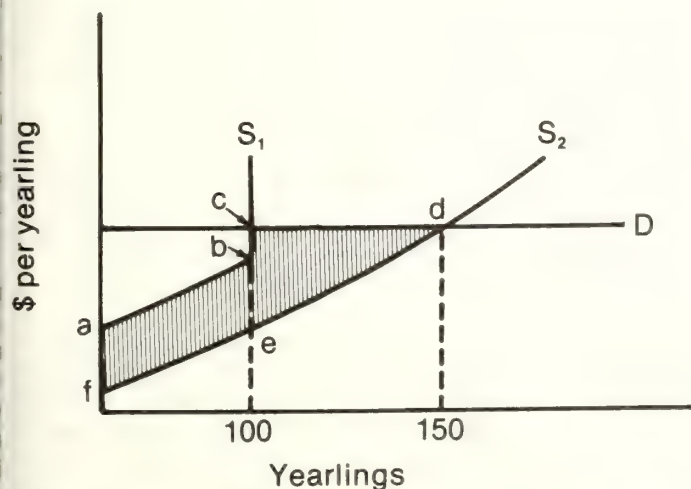


Figure 7.—Demand and supply schedules for a ranch representing a change in net income with increase in available forage.

net income (area bcd). The entire change in net income would then be the sum of these two areas (shaded in figure 6).

3. A combination of situations one and two: A change in a forest product input, the availability of which was previously limited so as to constrain production, lowers production costs and eliminates the constraint on production. This may produce a combination of cost savings, production increases caused by the production cost decreases, and production increases caused solely by the increased input availability. For example, suppose that a rancher with an allotment for grazing cattle on public land is currently producing 100 yearlings per year, but could produce more given his capital structure if there were sufficient forage on the range. Reduction of the timber overstory might lower costs of production for the original herd by allowing greater animal weight gains per quantity of forage consumed, because the livestock would not have to use as much energy finding forage (shown as the cost savings abef, figure 7), plus allow additional cattle to be grazed, further increasing income (area bcde). The entire change in net income is the shaded area in figure 7.

The change in net income is the change in total revenue minus the change in total cost (net of forest product input cost) for the firm or firms affected by some change in the quantity or quality of the input. As long as the price of the end product does not change, the unit change in revenue is the end product market price, and the change in total revenue is the market price times the change in output for the affected firms. Where several firms are affected, the total change in output would be the sum of the changes of the affected firms.

Comparability

There is a problem of comparability between the observation method and the change in net income method if the costs of the producers using the forest product do not reflect an equilibrium situation (a situation where marginal cost equals end product price). Consider the example of stumpage used to produce lumber. With the observation method, the unit change in producers' surplus of a small change in stumpage output (ΔPS_1) is calculated as

$$\Delta PS_1 = P_s - MC_s$$

where P_s is the competitive stumpage price and MC_s is the affected forest's marginal cost of providing stumpage. With the change in net income method, the unit change in producers' surplus of a small change in stumpage output (ΔPS_2) is calculated as

$$\Delta PS_2 = P_l - MC_l + P_s - MC_s$$

where P_l is the competitive lumber price and MC_l is the marginal cost of producing lumber of the affected firm(s). $MC_l - P_s$ is the marginal cost of producing lumber net of stumpage cost. If P_l does not equal MC_l for the firms from which lumber cost data are obtained, ΔPS_1 will not equal ΔPS_2 . P_l will not equal MC_l if the firms are not producing at their optimum levels, which is a common situation in the short run.

The estimate of ΔPS_1 will be less than the estimate of ΔPS_2 , even if the relevant firms are producing at equilibrium levels, when average variable cost is increasing and is used as the estimate of MC^l .

Changing Product Price

When changes in product output are large enough to affect product prices, the valuation problem becomes considerably more complex. Reduced product prices signify benefits to consumers and change in revenue to producers. Although only some of the producers in a given market may be directly affected by a change in the quantity or quality of some forest product, all producers in the market are affected by changes in end product price.

How well do the methods described above apply when forest or end product price changes as a result of a change in forest product output? The observation method cannot be used because we cannot observe the new price until it happens. The cost savings method circumvents the problem by definition—it only applies where the output quantity of the end product is constant, making the shape of the demand curve irrelevant. The change in net income method does not apply because the change in net income (the producers' surplus) for the firms affected by the change in output of a forest product would represent only part of the benefit, since consumers would also benefit, and because any firms in the market not directly affected by the change in output of the forest product would experience a decrease in net income because of lower end product prices.

An Approach Where the Forest Product Is Sold in a Competitive Market

Where the forest product is exchanged in a competitive market, and any products produced from the forest product are exchanged in competitive markets, valuation of the change is possible if both the prechange and postchange prices of the forest product are known. The prechange price is determined by observation of market data describing the existing situation. The postchange price depends on consumer tastes and preferences, availability and price of substitutes, prechange price, and change in quantity.

Economists use the concept of price elasticity to describe the price-quantity relationship, and thus the slope at specific points along the demand curve. Price elasticity is by definition the percentage change in quantity purchased (caused by a change in price) over the percentage change in price. For example, if an increase in the quantity supplied of some product resulted in a 5% increase in purchases and caused a 5% drop in price, the elasticity of that portion of the demand schedule is 1.0. If price dropped 10% with a 5% increase in quantity supplied, the elasticity of the relevant portion of the demand schedule is 0.5.

The postchange price can, therefore, be estimated if the analyst can estimate price elasticity for the expected change in quantity. While estimation of price elasticities is a complex topic beyond the scope of this paper, it should be mentioned that the analyst's first approach is to look for past studies which have developed demand schedules, or portions thereof, for the product and situation in question. This was the approach taken, for example, by Martin et al. (1978) in their estimate of the aggregate value of beef produced by the Arizona cattle industry. Using a small interval of a demand schedule of U.S. beef, they estimated that the average U.S. beef price would rise from \$0.986 per pound to \$0.997 if the Arizona beef industry suddenly disappeared.

With the constant product price situation it is sufficient to consider only the demand and supply schedules of the firms (e.g., timber mills, public forests) which are affected by the change in the forest product. Where the relevant price changes with the change in quantity of the forest product, one must consider the demand and supply schedules for the entire market, even though only some of the firms are affected by the change in the forest product.

For example, consider figure 8, where the hypothetical market is at equilibrium at point *a*, with 100 MBF of stumpage selling at \$10 per MBF. Assume that the elasticity of demand has been estimated and that the demand curve is linear over the relevant output range. Assume further that S_1 is the current market supply curve and that one of the "firms" in the market, the Ponderosa Forest, is planning to increase production by 20 MBF per year at a cost to the forest of \$6 per MBF (i.e., the Forest is experiencing constant costs, depicted by the horizontal segment *fg*), and that the costs of the Forest's inputs are competitively determined.

With the increase in output by the Ponderosa Forest, market equilibrium is at point *b* in figure 8. The change in producers' surplus is area *feb**g* - area $P_1aeP_2 \cong \$60 - \$95 = -\$35$. The change in consumers' surplus is $P_1abP_2 \cong \$105$. The net change in surplus is thus *fabg* = $\$105 - \$35 = \$70$. Note that, assuming S_1 and S_2 are parallel straight lines, area *fabg* is equivalent to area *hbcj* (since *facg* is equivalent to *hacj*) and thus that the surplus is more easily calculated as $((\$10 + \$9)/2 - \$6)(20) = (\$3.5)(20) = \$70$.

The critical problem with this approach is that the new equilibrium (*b* in figure 8) must be known, which requires knowing not only the elasticity of demand for the relevant range, but also the slope of the supply curve over the relevant range. As Cory and Daubert (1981) state, such supply information is difficult to estimate and rarely available.

Two approximations of the true surplus are commonly used. The first simply assumes that price does not change (that the demand curve is horizontal as shown by P_1c in figure 8), yielding a surplus estimate given by area *facg* = *hacj* = \$80 in figure 8. Using this approximation is equivalent to applying the observation method. The other approximation, recommended for federal water resource planning (U.S. Water Re-

sources Council 1979, p. 30251), suggests that the elasticity of demand information be used, but that it be assumed that the full increase in output (20 MBF in figure 8) comes about. This method yields a surplus estimate of area $adjh = \$60$ in the example. In all cases of normal (upward sloping supply and downward sloping demand) curves, the first estimate overestimates, and the second underestimates, the real surplus. Cory and Daubert (1981) show that the maximum error in using either of these estimates is equal to the difference between them, which is $\frac{1}{2}(Q_3 - Q_1)(P_1 - P_3) = \frac{1}{2}(20)(\$2) = \$20$ in figure 8. The error may or may not be significant, depending on whether the decision to which the value estimate is an input will change if the estimate is varied by the estimate of the error. As Cory and Daubert demonstrate, in only some circumstances is the error inconsequential.

An Approach Where the Forest Product Is an Input

Figure 8 can also be used to depict the situation where the forest product being valued is not sold in a competitive market, but is used to produce another product which is. Assume, for example, that D and S_1 in figure 8 depict the demand and supply schedules for lumber, that an increase in output of stumpage from a forest allows some firms to increase production of lumber by 20 MBF, and that these firms experience constant variable costs of \$6 per MBF. Area $fabg$ gives the correct measure of the gross surplus due to the increase in stumpage. The costs of the forest, necessary to bring about the increase, must be subtracted from this amount to give the net change in surplus.

Revenue and Cost Estimation

Application of the monetary valuation methods described in previous sections requires revenue and

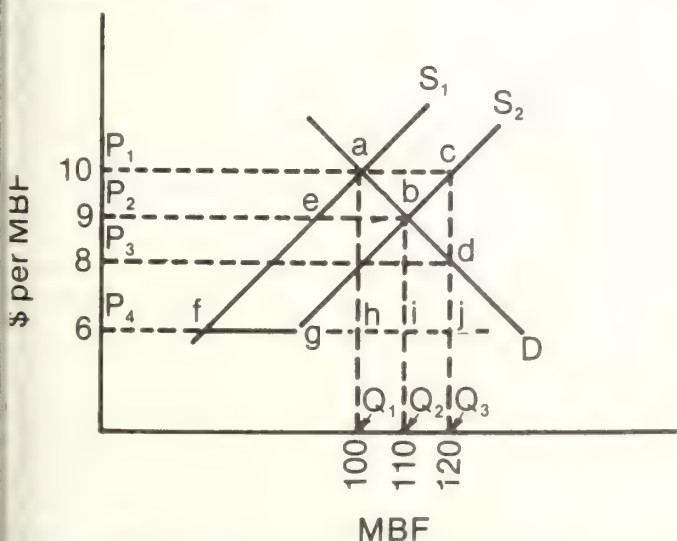


Figure 8.—Demand and supply schedules for a downward-sloping demand case. Adapted from Cory and Daubert (1981).

cost data. In this section, some sources of and problems with available data are discussed. Additional problems, introduced by inflation, are discussed in the following section.

Revenue Estimation

Changes in revenue caused by changes in output of a forest product depend on the price of the end product for the respective situation and method being used. Data on market prices are often available, especially for commodities which are sold in relatively competitive markets. Application of the observation method to stumpage and the change in net income method to lumber is facilitated by such publications as the Commerce Department's quarterly *Forest Products Review*, and the Forest Service's biennial *Demand and Price Situation for Forest Products* or quarterly *Production, Prices, Employment, and Trade in Northwest Forest Industries*. Common sources of farm product and livestock prices, for use of the change in net income method, are agricultural and statistical reporting services, generally connected with agricultural experiment stations. Eisenman et al. (1980) provide a guide to sources of data concerning timber, range, and water in the western United States. If price is expected to change as a result of the change in the forest product, price elasticity information may be needed in addition to data on actual prices.

Cost Estimation

To calculate how total cost will change with an increase in output, one must know for the affected firms or forests just what costs will change and how they will change. Total cost can be separated into fixed and variable costs. Fixed costs are those which do not vary as output varies in the short run, such as insurance, interest, and management salaries. Variable costs do vary as output varies in the short run; examples are wages and materials. Marginal cost is the change in total cost of a unit change in output. Because total variable cost, but not total fixed cost, varies in the short run with changes in output quantity, marginal cost changes as variable cost changes. If average variable cost decreases with a change in output, marginal cost is less than average variable cost, and if average variable cost increases, marginal cost is greater than average variable cost. If average variable cost is constant over some range of output, marginal cost is equal to average variable cost.

The change in total cost with a small change in output is approximated by the marginal cost times the output change. Unfortunately, marginal cost data are rarely available, forcing the analyst to rely on average cost data. As described above, where average variable cost is constant (the average cost curve is horizontal) over the relevant range of output, average variable cost equals marginal cost and, thus, can be used to estimate accurately the change in total cost. Several

empirical studies of cost curves of individual firms have been made in recent years. "Most of them suggest that short run marginal cost curves are horizontal over the usual range of output . . ." (Friedman 1976, p. 143).

For many cases of lumber, livestock, and crop production, it seems reasonable to assume that average variable cost is constant over relatively small changes in production. The implicit conditions of constant average variable cost with a change in output are constant prices of all variable inputs and constant returns to scale. The first condition is quite reasonable where changes in output are small relative to the total market quantity supplied. The second condition depends on the fixed plant of the individual firms. Some firms have a mix of fixed cost inputs, such as fences, water developments, corrals, horses, etc. for a ranching firm, which allow considerable change in output without changes in average variable costs. Others do not. The case where the average variable cost of producing an increase in output is the same as that for the original output quantity is depicted in the move from 5 to 6 MMBF in figure 5. The total change in cost in this case is equal to average variable cost at 5 MMBF times the change in output.

If average variable cost is expected to increase for the relevant change in output, one must estimate the change in order to calculate the change in total cost. As stated above, this is difficult because of the lack of marginal cost data. Analysts often ignore a possible increase in average variable cost for an output change if the increase is considered minor. Where average variable cost is increasing for the specified change in output, prechange average variable cost will underestimate marginal cost, and the estimated change in net income (and thus the benefit), will be overestimated. For example, consider the increase in output from 6 to 7 MMBF in figure 5. The rising marginal cost curve over this range implies that average variable cost is also increasing (i.e., if total cost increases by continuously increasing amounts with each additional unit of output, average variable cost must also be increasing). The actual change in total cost for the 1 MMBF increase is about \$450,000. Applying prechange average variable cost to the change results in an estimate of \$400,000 for the change in total cost.

For public agencies, a common problem in cost estimation is that cost data for individual firms are rarely available. Rather, the available data represent an average of several firms or are in terms of "representative" firms. Often two to four firms are chosen to represent a range of firm sizes. For example cost data might be estimated for three representative ranches, of 100 animal units, 250 animal units, and 600 animal units. The cost data for each representative firm could have been based on the costs for specific firms, but more generally are based on data from several firms of the approximate size of the representative firm. Thus, the analyst generally must estimate the costs of the firms affected by the change in forest product output from cost data which only approximate the costs of the affected firms.

The distinction between fixed and variable costs is sometimes misleading. It is possible that costs normally considered fixed will change with a specified change in forest product output. For example, in order for a rancher to properly utilize an increase in available livestock forage, additional fences and water development may be necessary. Such developments are considered part of the fixed ranch investment because they are durable and not divisible to the animal unit level. However, as herd size increases, points will be reached when additional fixed cost inputs are necessary. If some fixed cost items change as a result of the change in forest product output, those fixed costs become variable from the standpoint of the derivation of the value of the change in forest product.

Even if obvious changes in fixed costs are accounted for in a valuation effort, the resultant monetary value must still be considered a short-run value. In the long run there may be other changes in the cost structure of the firm or forest, perhaps as a result of new technology. Such changes can rarely be predicted and may have little or no relationship to the forest product change being valued. Nevertheless, they may alter, ex post, the value of the change in forest product output. If the ex post change in the monetary value occurs within the planning horizon in which the monetary value is being used, an error is introduced.

Two problems in calculating net change in surplus arise because of the long production periods for some forest products and because of the multiproduct nature of most public forests. To examine these problems, consider a forest producing timber and providing wildlife habitat and recreation opportunities. Some of the forest management costs, such as the cost of sale administration, occur at the time of harvest and are totally assignable to the harvest. Others, such as the cost of pruning, while perhaps totally assignable to timber production, precede commercial harvests, and may only occur once or twice per rotation. The costs which are not incurred at the time of harvest but which are directly attributable to the resultant stumpage must be allocated to the harvests they support and expressed in comparable dollars to those of the harvest to which they are allocated. While this can be done, it usually requires somewhat arbitrary decisions about the proper allocation and about the proper discount rate.

The other, and more serious, problem is that other costs may not be attributable to only one product. For example, precommercial thinning may affect some wildlife species, and roads built to facilitate harvest may affect access for recreationists. There is no correct way to allocate such costs among the various forest products. The only theoretically neat way around the dilemma is to compare the multiple benefits and costs of entire land management alternatives. In such a comparison, all relevant costs and benefits are included, but ambiguous cost allocation efforts are avoided. As long as all costs are included in the overall analysis, estimates of gross change in surplus are adequate measures of value.

Price Changes Over Time

The procedures described above for valuing changes in forest product output rely on estimates of market prices which apply to a specific time period. Commonly this period is a calendar year which has been chosen as the base year for the planning exercise. Prices generally change considerably over time, which causes problems when analysts (1) use data from past years to estimate prices for the base year and (2) apply the base year estimate to future years.

Base Year Estimates

Generally the analyst needs to calculate a shadow price which represents what the base year price would be in the absence of short-term abnormalities caused by weather, foreign demand, and other fluctuating influences. It is generally safer to base this shadow price estimate on price data for several past years, rather than on just the most recent year, in the hope that short-term abnormalities will cancel out.

The simplest and least satisfying approach is to average the prices for several recent years. The most serious problem with this approach is that it ignores the influence of inflation (deflation), thereby underestimating (overestimating) the price. This problem can be largely corrected by updating each year's average price to the base year using factors which express the change in an appropriate price index, such as the wholesale commodity price index. That is, the factor for each year, to be multiplied times the actual year's price, is the base year price index divided by the price index for the respective year. Such indexes can be found in numerous publications, such as the Survey of Current Business published by the Census Bureau.

A more common procedure for estimating base year price is to calculate a linear or nonlinear trend line from data for recent years using simple linear regression. This method averages out short-term fluctuations, and also accounts for the general upward trend of inflation. This method too, however, has problems. As Niehaus (1978) observed, it is adequate during periods of relatively stable prices, but is of limited value when prices fluctuate widely.

The weighted average approach, which combines elements of the inflation-adjusted average and the trend line, is sometimes used when the base year is also the current year. With this approach, the inflation-adjusted prices for each year are multiplied by the associated volume produced, for the market in question, to give total value by year. Regression is then used to predict the current year total value. Regression is also used to predict the current year total volume produced. Then the predicted total value is divided by the predicted volume to yield the predicted unit value. The rationale behind this approach is that unit value is in fact a function of volume produced, and that basing the value on predicted volume is more accurate than ignoring volume.

Niehaus (1978) describes more sophisticated approaches, such as the zero-one shift method and structural approaches. These approaches require a thorough knowledge of the markets for the products being priced, and are not of practical use to the analyst unfamiliar with such markets. However, the analyst may be able to rely on the expertise of others. The U.S. Water Resources Council, for example, publishes agricultural prices calculated using a weighted average technique (see, for example, U.S. Water Resources Council 1978).

Future Prices

In many analyses of alternatives for future land management, the base year price estimates are applied to future years, completely ignoring any possible inflation (or deflation) of those prices. This decision is based on the assumption that inflation will affect all relevant costs and benefits similarly, making inflation of no consequence for comparing alternatives. If the inflation of the relevant costs and benefits is that of the average of all goods and services, the "real" prices of those costs and benefits are said to be constant. However, if the price of a cost or benefit does not change as do the average prices of all goods and services, then its real price is said to change, and this real price change should be accounted for in the analysis.

Changes in real prices occur with changes in any of the determinants of the demand and supply schedules. For example, the real price of timber might rise if consumer tastes change favoring wood products over substitutes such as plastic and metal. Or the increasing scarcity of petroleum may raise the cost of petroleum products, causing greater demand for wood products as fuel and thereby raising real prices of wood products. On the other hand, improvements in harvesting and milling technology, which allow reductions in lumber production costs, may cause corresponding decreases in lumber prices.

Where there is strong reason to believe that the real price of some cost or benefit will change over the planning horizon, the analyst may want to include this change. Estimates of future real price changes are usually based on past real price changes and an understanding of the demand and supply situations for the product in question (and, therefore, for its substitutes). There is strong evidence, for example, that the real price of wood products will rise. The real price for wood products nationwide has risen an average of about 1.4% per year over the past 100 years, with real lumber prices increasing an average of 2.2% per year over the same period (Manthy 1978).

The choice of a specific real price rise to apply to future years is guesswork, however. Numerous problems arise. For example, sawtimber prices have risen faster than the average, but pulpwood prices have risen slower—would the products from the planning area be of the same composition as the national average? Real sawtimber price rises during the past

10 years have been much higher than the long-term average rise—is this short-term trend a more realistic example of the future than the long-term trend? Will the increasing price of wood products make substitutes, heretofore not used because of prices, more viable alternatives to wood, thereby reducing increases in the demand for wood products? Clearly, any estimates of future real price changes are risky, requiring that the results of a comparison of alternatives be subjected to sensitivity analysis to make visible the importance of real price change assumptions.

Another cause of changes in resource values is changes in the capital structure of firms which use the resources as inputs in the production of end products. Consider a group of farms which would use additional runoff to produce additional outputs of alfalfa and barley. The change in net income to these farms would be different if they changed the irrigation systems to more efficiently use water and power. The water value derived using the change in net income method based on the original capital structure would be different if the new structure were in place. Such changes are difficult to anticipate and measure.

PART II: EXAMPLES OF MONETARY VALUATION OF TIMBER, FORAGE, AND WATER IN CENTRAL ARIZONA

The constant product price methods described in Part I are demonstrated here using numerous examples of changes in stumpage, livestock forage, and water runoff outputs from central Arizona forests. Realistic land management planning decisions regarding these forest products in central Arizona are not likely to require use of changing product price methods. The reader might wish to consult Cory and Daubert (1981) for an example of the use of such methods.

In all cases, gross monetary values are estimated. Such values do not account for the administrative and other management costs to the forest of providing the changes in forest output. These forest costs would have to be subtracted from the gross values in order to obtain net values.

Numerous externalities, some positive and others negative, are associated with forest activities to change outputs of stumpage, forage, and water. For example, changes in timber harvest, livestock grazing, and water runoff may all affect onsite wildlife habitat, scenic quality, and soil fertility. Possible offsite externalities include changes in air pollution from milling of lumber and changes in recreational use of streams and lakes or reservoirs. Such externalities are real costs or benefits which should be accounted for in the overall planning effort for which the monetary values derived using the methods described herein are estimated. It is not the purpose of this paper, however, to deal with such costs and benefits.

TIMBER STUMPAGE

Market Characteristics

Arizona timber is sold as sawtimber, pulpwood, Christmas trees, and firewood. Christmas trees and firewood account for very little of the total standing timber sold and will not be considered here. Sawtimber (the trees of 11 inches or greater in diameter at breast height) has accounted for over 85% of the total volume of sawtimber and pulpwood stumpage cut in recent years. The sawtimber is mainly used by Arizona mills to produce lumber, but a small amount of poles and molding are also produced. The pulpwood, as well as much of the chips left over from lumber production, are used by the pulpmill to produce kraft liner board and newsprint.

The stumpage market in Arizona fails to meet three of the four conditions of competition. First, there is not a large number of buyers and sellers. Only 4% of the commercial forest land in Arizona is privately owned. Sixty-nine percent is on national forests, 26% is on Indian reservations, 1% is on state land, and 0.2% is managed by the Bureau of Land Management. Furthermore, the number of buyers is small and has gradually declined. In 1946 there were 66 sawmills producing lumber in Arizona, in 1965 there were 25 and in 1974 there were only 16. Nine of 16 sawmills were owned by four firms, and these four purchased nearly all the timber from national forest land.

The small number of buyers is reflected in bidding behavior for national forest timber. For 1960-1974, timber sale records for Arizona national forests show that only 24% of the sales had more than one bidder and that only 13% sold at greater than one percent above the appraisal value. For pulpwood, the buyers market is monopolized, because there is only one pulpmill close enough to the raw material to purchase it economically.

Second, there is a lack of free entry. Entry into the sellers market is limited by public ownerships of nearly all the commercial timber. Entry into the buyers side is limited on national forests by institutional arrangements and on Indian reservations because most timber is harvested by tribal enterprises. The Colorado Plateau Pulpwood Agreement of 1957, between the USDA Forest Service and Southwest Forest Industries, assures the firm a 30-year supply of pulpwood at an administered price and effectively eliminates other buyers. Until it was tentatively abolished in 1980, the Flagstaff Federal Sustained Yield Unit, established in 1949 under the Federal Sustained Yield Act of 1944, required that 85% of the allowable cut from the Unit be given primary manufacturing within the city of Flagstaff or three miles thereof and that the remaining 15% be offered for sale to other purchasers without regard to location of manufacture.

The third competitive market condition is product homogeneity. The market fails this test because each sale is unique: volume, timber species, wood quality, accessibility, and other characteristics differ from one sale to the next.

The fourth condition, perfect knowledge, is fairly well met. Market information appears to be adequate. National forest timber sales are advertised, and information, such as the volume of timber sale, its appraised price, the location of the sale, and the physical characteristics of the timber, is readily available. Thus, all potential buyers of public timber within the specified region are given equal market information about the appraised price and timber characteristics.

While the Arizona stumpage market exhibits little competition, the markets for wood products are generally very competitive. According to Mead (1966) "The United States timber industry is frequently cited by economists to illustrate a real world approximation to the model of pure competition...we find that individual firms, even the largest, face a perfectly elastic [horizontal] demand curve for their lumber, and that the profit rate is no higher than that hypothesized by the competitive model." Although the stumpage market is often a local market, lumber products are sold nationwide. For example, lumber producing firms in Arizona sell ponderosa pine lumber throughout the country at competitive market prices, and Arizona businesses which use lumber as an input buy lumber from other parts of the country as well as from local mills. Because there are thousands of sellers and buyers of lumber products interacting with each other in the market, no single buyer or seller can change the lumber product price.

There are no institutional barriers to exit and entry into the lumber industry. There is a free flow of information on price and product quality throughout the country. Several wood product associations and timber purchaser associations attempt to enforce uniform lumber standards and grading rules around the country, enhancing product homogeneity.

The basic wood products, such as pulp and lumber, are, in turn, used to produce a number of products, including paper, furniture, pallets, and buildings. The markets in which such products are exchanged are all rather competitive.

Valuation

Two examples of valuation are presented here. The first is of a change in sawtimber quantity, and the second a change in pulpwood quantity.

A Change in Sawtimber Quantity

Let us assume that a national forest in Arizona is considering several alternatives for future management of the forest, and specifically that alternative B will increase the quantity of timber available for harvest over that with alternative A, which is a continuation of current management direction (the "without" alternative). Further, assume that the average quality of the timber is unaffected by the quantity change (step 1, p. 5) and that the increase is

located in numerous prospective sale areas throughout the forest and would most likely be harvested as an additional 100 MBF per year and used to produce lumber (step 2). The forest planning team needs an estimate of the value to society of the additional 100 MBF per year from the efficiency standpoint (step 3).

The question is (step 4), "What valuation method should be used?" The observation method is a poor choice in this situation. Although competitive markets for ponderosa pine stumpage do exist, and average stumpage prices from such markets are published, it is very difficult to decide which market best represents the resource in question. For example, in the third quarter of 1977 average ponderosa pine stumpage prices for national forests in the Northwest averaged \$147 per MBF and ranged from \$59 to \$223 per MBF (Ruderman 1978).

Because of the market characteristics, derivation of the sawtimber stumpage value from the value of lumber is the most promising approach. The change in net income method applies: The end product and all subsequent products are exchanged in relatively competitive markets, the increase is too small to change the price of the end product, and the producers' variable inputs, other than stumpage, are exchanged in at least relatively competitive markets. The most appropriate model for application of the change in net income method is figure 5.

Each month the Western Wood Products Association publishes a price trend index for ponderosa pine based on lumber transactions throughout the West. While this is useful in updating regional prices, the west-wide prices themselves do not apply to specific regions or forests. The most localized lumber price data for Arizona are those published by the Forest Service's Southwestern Region, which encompasses Arizona and New Mexico. Each year the Southwestern Region publishes selling price per MBF for four different species, weighted by grade volumes. Thus the average price is that for the log of average grade.

In order to estimate a ponderosa pine lumber price for 1977, we might calculate a trend level price based on average prices for the 10 most recent years, as listed here in lumber tally (LT) terms:

Year	\$/MBF LT
1967	78.20
1968	95.95
1969	116.99
1970	97.74
1971	117.63
1972	140.78
1973	180.90
1974	167.58
1975	149.62
1976	197.54

A straight line least squares fit yields a 1977 price estimate of \$200 per MBF LT ($r^2 = .84$). However, there is some evidence to suggest that price changes in the 1960's are a poor basis for prediction in the foreseeable

future. Straight line least squares fit on data for 1970-76 gives a 1977 price estimate of \$206 per MBF LT ($r^2 = .74$). And, because a plot of the actual prices showed some nonlinear tendencies, the data were fit to an equation of the form $\text{price} = a(\text{time})^b$. This yielded an estimate for 1977 of \$195 per MBF LT ($r^2 = .84$). A corresponding inflation-adjusted price estimate, based on 1970-76 data, gives a 1977 price estimate of \$210 per MBF LT. And the weighted average approach, using a straight line fit to predict the 1977 total value and volume, gives a 1977 price estimate of \$215 per MBF LT. Based on these estimates, it seems reasonable to assume that the price will, in the absence of short term fluctuations, be between \$195 and \$215 per MBF LT. (The actual average 1977 price was \$233 per MBF.)

The following types of costs are involved in the cost estimates. Variable costs include all expenses which vary in the short run depending on the quantity of production, where the short run is a logging season for logging operations or fiscal year for a mill. In the logging operation variable costs include such items as felling, bucking, skidding, loading, and hauling. They also can include expenses necessary to deal with damage which the harvest causes to the site or the transportation system, provided such expenses vary as harvesting level varies (e.g., road maintenance and slash disposal). In the mill, the variable costs include labor, materials, power, and other costs which vary as output varies for all operations in the log yard, from yard, to sawmill, to greenchain, to shipping.

Fixed costs include all expenses which do not vary as output varies in the short run (e.g., administrative salaries, property taxes, depreciation, and insurance). Fixed costs also include road construction, sale administration, and other costs which may not vary significantly with sale volume.

In the short run, total variable cost will increase for firms which harvest and mill the additional stumpage. Even if it were certain which firms would harvest and mill the additional stumpage, cost data for the individual firms would most likely be unavailable. The only readily available cost data for Arizona lumber firms are published by the Forest Service's Southwestern Region. These data are compiled in two parts. The harvesting costs are simple averages of harvesting firms which contribute their cost data, with most firms in the region contributing. The milling (manufacturing) costs are the averages of the firms contributing, weighted by mill production. Although the Forest Service collects cost data from individual firms in order to calculate these regional averages for the purpose of timber sale appraisal, the individual firm data is proprietary and supplied to the Forest Service with the understanding that only averages will be published and used.

Ideally, the marginal cost would be known for each individual harvester and mill which would be affected by the change in harvest. Because only average cost data, averaged over most operators and mills in the region, are available, it is important to determine whether or not the average variable cost data avail-

able actually approximates the relevant marginal costs? This question can be approached in two parts. First, "Will the average variable cost of each affected operator and mill approximate its marginal cost?" Second, "What problems are introduced by averaging over most operators and mills?"

Economic theory of the firm is of some help in answering the first part. First, consider the harvesting operation. Typically, variable costs account for 80% or more of total costs. Furthermore, vehicles and machinery, the major components of fixed cost, are relatively easily and quickly bought and sold, and thus may be treated as variable costs for all but the very short run. Therefore, only the inability of management to efficiently handle increased output would cause average variable cost to increase significantly as output increases. This is not likely to be the case, leading one to the conclusion that average variable cost is relatively stable with small changes in output, and that marginal cost is not significantly different from average variable cost (figure 9).

With milling operations, variable costs account for about 75% of total cost. In Arizona, all mills are typically producing at levels well below their stated capacity, evidenced by the fact that most mills work only one shift and none work more than two. This is because of the limited quantity of timber supplied from the national forests. This fact suggests that they are producing at levels where average variable costs are not changing much with changes in output—the capacity of the plants is not close to being taxed. Thus it seems reasonable to assume that the average variable cost curve is either constant or dropping or rising at a low rate, meaning that marginal cost approximates average variable cost. This is depicted by the shift from Q_1 to Q_2 in figure 9.

Now for the second part of the question, "What problems are introduced by using regional average costs?" If the analysis is regional in scale, involving timber harvested from all areas of the region, the error introduced by using regional average costs is probably relatively insignificant. However, if the analysis is of a very localized situation, where a limited number of firms are involved, the real costs of such firms may be quite different from the regional average. In this case, the error in valuation may be significant. Localized adjustments in some costs may be feasible, such as in costs for harvesting, hauling, and slash disposal, but

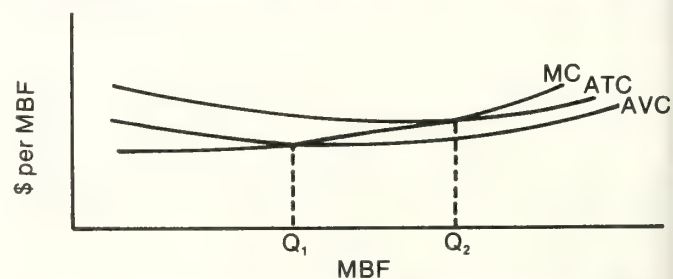


Figure 9.—Expected cost situation for harvesting firms—because average variable cost (AVC) changes very little within a reasonable range of production (Q_1 to Q_2), AVC at any one time approximates marginal cost (MC).

adjustments in milling costs are much more difficult to make. Here again a range may be more appropriate than just one best guess figure.

Proceeding with the example on the basis that regional average costs are appropriate, the following variable costs per MBF log scale (LS) for 1977 were calculated from a linear trend of costs for 1970-76:

Fall and buck	\$ 8.70
Skid	9.98
Load	4.48
Haul	12.80
Road maintenance	1.90
Slash disposal	10.01
Erosion control	.63
Manufacturing	69.19
Miscellaneous	2.21
Total	\$119.90

The corresponding fixed costs total \$46.72, resulting in average total cost of \$166.62 (the actual regional average cost in 1977 was \$167.19).

Converting the lumber tally selling prices of \$195 and \$215 per MBF to log scale, based on an overrun estimate of 1.25, yields end product selling prices of \$244 and \$269 per MBF. Subtracting out average variable costs yields a range of change in net income per MBF of \$124 to \$149. Thus, the gross value to society of the increase in harvest is from \$130 to \$149 per MBF. In the absence of simulations or other information about future prices, one may assume past trends will continue into the future. Based on past trends, the value can be expected to increase in real terms at a rate of 2.2% per year (Manthy 1978).

A Change in Pulpwood Quantity

Let us assume that an alternative timber management plan would increase the quantity of pulpwood available for harvest on an Arizona forest (step 1). The only use of harvestable pulpwood in Arizona is by the pulpmill in Snowflake, Ariz., in making liner board and newsprint. However, would this use really be affected by the increase in available pulpwood; that is, would the increase be harvested and milled (step 2)?

Historically not all the available pulpwood has been purchased. Thus, an increase may remain on the stump or merely substitute for other pulpwood which would have been harvested if the new supply did not become available. If it remains on the stump, it has no current value as pulpwood. If it substitutes for less accessible pulpwood, and is used to produce pulp products (step 3), it can be valued using a cost savings approach (step 4). The value is the harvesting savings, of from zero to about \$7.00 per cord and the hauling savings, of about \$0.13 per mile per cord. This is not a savings on all production, as depicted in figure 4. Rather it is a savings over a relatively small portion of the total production.

However, if future liner board and newsprint prices were to make greater pulpwood harvests attractive, the increases in available pulpwood could augment in value. If such were the case, the change in net income method would be the most appropriate valuation method. However, the unavailability of milling cost estimates for the mill in question precludes use of the change in net income method.

FORAGE FOR LIVESTOCK

Market Characteristics

The forage market is not very competitive, largely because of the small number of sellers and the lack of free entry. Nearly 82% of the land in Arizona is publically owned, and over 82% of the grazing in the state is on public land. For almost all of the public land, there is no forage market. Rather, the permittees are charged an administratively set fee per animal unit month (AUM) of grazing. While there have been some efforts on the part of some of the land management agencies to charge the "fair market value" for the forage, there is general skepticism that the administratively set fees approximate a shadow price for forage.

The buyers of forage on public land are the permittees who hold grazing permits. Such permits are generally held for long periods and are usually tied to private land holdings in the proximity of the permit area. As long as the permittees continue to properly use the forage, their right to the forage is not questioned.

A forage market exists for privately held forage. However, while there are no restrictions to entry of the private forage market, the logical buyers of grazing rights are owners of adjacent or nearby rangeland, limiting the number of practical buyers for any particular grazing right.

The livestock market, on the other hand, is very competitive, not only in Arizona, but throughout the United States. Ranchers in Arizona compete with each other and with ranchers from neighboring states in selling their livestock. Cattle feed lots are numerous. Livestock are sold both by auction and directly from the ranches. There are large numbers of buyers and sellers, entry and exit to the market is not restricted except for public land on the sellers side, product information is ample, and the products are rather homogeneous.

The principal product made from livestock is meat. As with most foods, the market for meat is highly competitive.

Valuation

The most common valuation example will be considered here—that of an increase in forage quantity (step 1). The site used here is national forest land in the Salt-Verde Basin, an 8.4 million acre area in central Arizona. National forests cover 64% of the Basin, and nearly all the national forest land in the Basin is grazed. A change in forage quantity will principally af-

fect cattle, deer, and elk (step 2). Let us assume that forest planners want to know the unit value in terms of livestock grazing of a marginal increase in forage on national forests in the Basin (step 3)?

Two methods could be used to approach this problem, the observation method and the change in net income method (step 4). The data supporting the observation method are the average annual private lease rate of an AUM, published for selected states by the USDA in an annual publication titled "Farm real estate market developments."

The rate for Arizona for the ten years prior to 1977 was as follows:

1967	\$2.84
1968	3.16
1969	2.91
1970	3.44
1971	2.78
1972	2.52
1973	2.79
1974	3.21
1975	4.60
1976	4.15 (estimate)

Unfortunately, 1975 was the last year for which a separate Arizona rate was published. Data for 1967-76 yields a 1977 value of \$3.94 per AUM with a poor linear fit to the data ($r^2 = .35$). Data for 1971-76 yields a value of \$4.69 per AUM with a much better fit ($r^2 = .74$). The value for the average grazing land on private land in Arizona probably lies between about \$4.00 and \$4.70 per AUM.

It is safe to say that the average public grazing land in Arizona is of lower quality than the average private grazing land, because much of the public grazing land is in timbered areas or on steeper slopes than is most private grazing land. This suggests that the gross value for the national forest land in the Salt-Verde Basin is lower than the \$4.00-\$4.70 per AUM estimate.

Use of the change in net income method requires much more effort than use of the observation method. Ranchers' income will change with an increase in forage for livestock grazing if the additional forage allows an increase in grazing. If so, the change in net income for an affected ranch equals the market value of the additional animals produced minus the change in total cost associated with the additional animals. As long as the prices of the ranchers' variable inputs are determined competitively, the change in net income is an appropriate measure of the gross change in producers' surplus.

Mathematical optimization models, such as linear programming, are sometimes used to model rancher operations with changing forage availability. This approach has the potential of more accurately estimating the change in net income than the simpler approach demonstrated here.

Because the livestock market is competitive, and because the change in total market production associated with a small increase in forage in the Salt-Verde Basin is not expected to be large enough to affect livestock prices, the market prices for the base situation are appropriate to use in calculating the unit value to society of the increase. The Arizona Crop and Livestock Reporting Service (1978) reported the following average sale price per pound for range fed cattle for the ten years prior to 1977:

	Calves	Yearling steers and heifers	Cows
1967	\$0.252	\$0.242	\$0.157
1968	.265	.254	.168
1969	.299	.288	.193
1970	.329	.288	.198
1971	.359	.311	.209
1972	.432	.348	.239
1973	.536	.438	.297
1974	.363	.406	.237
1975	.284	.401	.205
1976	.341	.378	.254

Based on these data, the trend line (least squares linear regression) prices for 1977 are \$0.410 for calves, \$0.446 for yearlings, and \$0.272 for cows (the actual 1977 prices were \$0.375, \$0.391, and \$0.243, respectively). Conklin and Young (1977) suggest a method which yields similar results.

The marginal cost of the affected ranches is the most appropriate cost to use to calculate the change in total cost, but marginal cost data are not available. The common assumption in this case is that average variable cost approximates marginal cost, which is equivalent to assuming constant marginal cost (similar to the shift from 5 to 6 MMBF in figure 5). This assumption is generally considered safe for ranching enterprises, but certain adjustments from the common categorization of variable costs for ranching operations are necessary to calculate the marginal cost for public land planning.

First, the variable costs of ranches using public grazing land typically include livestock taxes and grazing fees. Although these items are out-of-pocket costs for the ranchers, they are merely transfer payments from the point of view of society, and are excluded from calculation of the change in net income when deriving the marginal value of forage to society. Second, bulls are typically considered a fixed cost of ranching operations. However, the number of bulls maintained usually varies with the size of the cow herd. If this, or any other "fixed" cost (fences, water developments, horses, etc.) changes with the predicted change in production, the change becomes a variable cost for the calculation of the change in net income. Finally, the interest on the investment in the breeding stock is often listed with fixed costs. However, as the size of the breeding stock changes to allow the change in produc-

on, associated interest changes also change, and this change must be accounted for in calculating the change in net income.

Central Arizona ranch budgets are available from two recent studies. Martin and Snider (1980) calculated 1977 budgets for four representative yearling ranching operations representing ranching throughout the national forests in the Salt-Verde Basin. Menzie and Archer (1975) calculated a 1974 budget for a representative cow-calf operation. The results from each of these studies are used here to estimate the change in net income.

As an example of the yearling budgets, consider table 1, which lists the variable costs for the 299 animal unit ranch. A \$12,000 charge for the owner's labor is included. For deriving the marginal value of forage from society's viewpoint the average variable cost per AUM is \$11.54 $((\$48,251 - \$1,159 - \$5,699)/(299 \times 12))$.⁵

The annual returns from the 299 AUM ranch are estimated as follows:

Cull cows	19 × 850 lbs × \$0.27/lb. =	\$ 4,361
Yearling heifers	49 × 580 lbs × \$0.45/lb. =	12,789
Yearling steers	74 × 620 lbs × \$0.45/lb. =	20,646
		<u>\$37,796</u>

⁵This analysis is based on the assumption that a 299 animal unit ranch actually consumes 299 animal units of forage; that is, that the method of accounting for animal units accurately reflects the forage consumed. Martin and Snider (1980) assume otherwise.

This return, equivalent to \$10.53 per AUM, minus the average variable cost of \$11.54 per AUM, yields a best guess gross value per additional AUM of forage of -\$1.01. The values for the four representative ranches are summarized in table 2 for highs, lows, and best guesses of cattle selling prices.

If the alternatives being analyzed were such that specific ranches could be isolated, then each affected ranch could be compared to one of Martin and Snider's four representative ranches. If one wanted an average value for ranches on national forests in the Salt-Verde Basin, a weighted average value could be calculated using the proportion of the total AUM's associated with each representative ranch. From table 3, the four ranches represent 18%, 22%, 27%, and 33%, respectively, of the total grazing on national forest land in the Basin. With these weights, the best guess of the average gross value of forage in the Basin is -\$0.85 per AUM.

The representative cow-calf ranch is a 368 animal unit operation. Annual returns in 1977 dollars are as follows:

Cull cows	30 × 850 lbs. × \$0.27/lb. =	\$ 6,885
Steer calves	80 × 385 lbs. × \$0.41/lb. =	12,628
Heifer calves	120 × 430 lbs. × \$0.41/lb. =	21,156
		<u>\$40,669</u>

This is equivalent to \$9.21 per AUM. Total variable cost, updating from Menzie and Archer (1975) using an inflation factor of 1.21 as calculated from the whole-

Table 1.—Variable costs for a 299 animal unit central mountain cattle ranch, 1977¹

Item	Explanation	Cost	(\$)
Feed			\$ 4,422
Alfalfa hay	9 tons @ \$65/ton	\$585	
Grain	2 tons @ \$135/ton	270	
Mineralized salt blocks	48 cwt. @ \$4.00/cwt.	192	
Range cubes (supplements)	450 cwt. @ \$7.50/cwt.	3,375	
Labor			13,200
Owner	Full time @ \$1,000/month	12,000	
Seasonal	2 man-months @ \$600/month	1,200	
Vehicle (gas, oil, repairs)			5,835
Utilities \$135 per month			1,620
Livestock taxes ²			1,159
Bulls		146	
Cows		625	
Yearlings		387	
Grazing fees			5,669
Veterinary			330
Repairs on capital investments			1,710
Insurance			943
Miscellaneous expense			110
Brand inspection		35	
Bookkeeping, dues, subscriptions, etc.		75	
Interest on borrowed operating capital ³			\$1,150
10% × 1/2 (22,998)			
Normal variable costs			36,148
Variable "fixed" cost—bulls			1,087
Opportunity cost—interest on bulls, cows, and yearlings			11,016
Total variable costs			<u>\$48,251</u>

¹Adapted from Martin and Snider 1980.

²\$9 per \$100 assessed valuation: Assessed at 18%

³\$22,998 excludes owner labor.

Table 2.—Marginal value of forage for four representative ranches, Salt-Verde Basin of Arizona, 1977

	151 ¹ AU's			299 ² AU's			468 ³ AU's			701 ⁴ AU's		
	High ⁵	Best guess ⁶	Low ⁷	High	Best guess	Low	High	Best guess	Low	High	Best guess	Low
Gross return per AUM ⁸	14.09	10.56	7.96	14.05	10.53	7.94	14.09	10.57	7.97	14.13	10.60	7.99
Variable cost per AUM ⁹	15.49	15.49	15.49	11.54	11.54	11.54	11.16	11.16	11.16	9.34	9.34	9.34
Net per AUM	-1.40	4.93	-7.54	2.51	-1.01	-3.60	2.93	-0.59	-3.19	4.79	1.26	-1.35

¹Cattle sales of 10 cows, 25 yearling heifers, and 37 yearling steers.

²Cattle sales of 19 cows, 49 yearling heifers, and 74 yearling steers.

³Cattle sales of 30 cows, 77 yearling heifers, and 116 yearling steers.

⁴Cattle sales of 45 cows, 115 yearling heifers, and 175 yearling steers.

⁵Highs are based on selling prices of \$0.60 per pound for yearlings and \$0.36 per pound for cows.

⁶Best guesses are based on selling prices of \$0.45 per pound for yearlings and \$0.27 per pound for cows.

⁷Lows are based on selling prices of \$0.34 per pound for yearlings and \$0.20 per pound for cows.

⁸Cattle weights of 850 lb., 580 lb., and 620 lb. for cows, yearling heifers, and yearling steers, respectively.

⁹From Martin and Snider (1980), excluding livestock taxes and grazing fees and including allowances for owner labor, and depreciation and interest on breeding stock.

sale commodity price index, and including \$12,000 for operator labor, equals \$47,478, which is equivalent to \$10.75 per AUM. This results in a gross value of additional forage of -\$1.54 per AUM.

A recent study⁶ of ranching in Colorado offers an opportunity to check the costs and returns upon which these values are based. The 1977 Arizona ranching cost estimates are generally lower than those for similar sized ranches in Colorado, while the returns are comparable. Thus, we have no evidence that the Arizona costs were overestimated or the values underestimated.

The best guess of the gross marginal value to society of forage for livestock on national forests in the Salt-Verde Basin varies from no value for the smaller ranches to \$1.26 per AUM (1977 dollars) for large ranches (table 2), with no value on the average. The highs range from no value for the smaller ranches to \$4.79 per AUM for the large ranches, with a weighted average value of \$2.67 per AUM.

The values are very sensitive to livestock price fluctuations (for example, see Martin and Snider 1980). Although applying the trend lines calculated from 1967-76 prices to 1977 overestimated actual prices, the trend lines underestimated actual prices for 1978 through 1980 by from 10 (yearlings in 1978) to 50% (calves in 1979). If a strong case can be made that the actual 1977 price was unusually low and did not represent future conditions, then perhaps the high estimate is more accurate than the best guess. In any case, sensitivity analysis should be used to determine how sensitive the results of a comparison of alternatives is to the forage value.

The negative marginal values of forage on the smaller representative ranches may be unfortunate, but not unreasonable. The marginal value of forage to society calculated here is not equal to the change in rancher's income from, say, a one AUM increase in forage. The interest and depreciation costs for

⁶From a report to the U.S. Forest Service, Bureau of Land Management, and Colorado State Experiment Station by E. T. Bartlett, R. G. Taylor, and J. R. McKean of the Colorado State University Department of Range Science, titled "Impacts of Federal Grazing on the Economy of Colorado," August, 1979.

breeding stock included as variable costs to derive the marginal value are real opportunity costs, but they are not necessarily out-of-pocket costs to the rancher. These costs range from 22 percent (for the 151 animal unit ranch) to 36 percent (for the 701 animal unit ranch) of total variable costs. The best guess of the actual change in the rancher's income for the 299 animal unit ranch, for example, is \$10.53 minus 10.07, or \$0.46 per AUM. Furthermore, the \$12,000 cost of owner's labor (table 1) is not necessarily an out-of-pocket cost (many owners of small ranches hold outside jobs to supplement their income).

Additional reasons exist which help explain the low returns to forage. Smith and Martin (1972) for example, interviewed a sample of Arizona ranchers and found most to be willing to accept low returns on their investment because of related benefits of owning and living on a ranch. And Martin and Jefferies (1966) concluded, "the relatively nonquantifiable outputs of farm fundamentalism and conspicuous consumption, as well as possibilities for the monetary outputs of tax shelters and ranch appreciation" help explain the prices paid for cattle ranches.

In applying the values to the future, the analyst may want to assume that the past real change in livestock values will continue in the future. In the absence of specific knowledge about the future, one is left with long term trends. Perhaps the most appropriate estimate of future price changes is the increase in real cattle prices over the past 100 years which has been 0.9 percent per year (estimated from Manthy 1978).

WATER RUNOFF

Water is a peculiar commodity which has received the attention of many writers, particularly in the arid West (see, for example, Kelso et al. 1974 and Young and Gray 1972). Pressures and opportunities for public investment in water-related facilities such as dams, irrigation systems, and drainage systems has given rise to a gradually unfolding set of federal regulations for planning such investment, beginning in the United

Table 3.—Allotments and permitted animal units on national forest land in the Salt-Verde Basin, 1977

Forest	Allotment size in animal units (AU's)								Total AU's
	0 to 190		191 to 349		350 to 585		586 to larger		
	Number	Mean	Number	Mean	Number	Mean	Number	Mean	
Kaibab	13	96	2	303	2	533	0	0	2,920
Coconino	35	76	8	268	5	432	3	666	8,962
Tonto	30	77	23	245	20	457	15	905	30,660
Prescott	8	111	6	273	0	0	0	0	2,310
Apache-Sitgreaves	14	104	3	273	1	439	0	0	2,714
Total	98	87	42	253	28	457	18	865	
Total AU's	8,562		10,626		12,805		15,573		47,566
AU's out of Basin	360		447		730		1,423		2,960
Total AU's in Basin	8,202		10,179		12,075		14,150		44,606
Percent of total	18		22		27		33		100

States with the Flood Control Act of 1936 and culminating, to date, with the Water Resources Council's Principles and Standards for Planning Water and Related Land Resources (1973) and the Procedures for Evaluation of National Economic Development Benefits and Costs in Water Resources Planning (1979). These documents provide useful guidance in developing planning guidelines for other resources. In addition, Young and Gray (1972) provide an excellent treatment of the economic value of water which should be consulted if the reader desires more detail than contained herein.

Market Characteristics

In Arizona, 89% of total water consumption is by the agricultural sector, with the remaining 11% consumed by the municipal and industrial sectors. However, the relative use by sector is not uniform across the state. The large population centers in the desert portions of the state are also the centers for most of the agricultural water use. Water use in many of the smaller cities and towns in cooler and moister portions of the state is almost entirely for municipal and industrial purposes.

The water market is not competitive. Some users pump water from their own wells. Elsewhere there may be a large number of buyers, but generally each buyer is dependent on only one seller. Supply of water in Arizona is dominated by municipalities, a few local public water developing organizations of water users (such as the Salt River Project), a few privately owned firms operating under public utility regulations, and individuals or business concerns that develop water for their own uses. The water supplying agencies are not owned by profit seeking firms. The self-supplying individuals and business concerns (typically farmers or miners operating their own wells or diverting water from streams) are single units, so they do not participate in any water market. The municipalities and organizations are users' cooperatives developing and supplying water for a specific group of users. Although

water is a relatively homogeneous product and knowledge is adequate, the water supply structure assures a noncompetitive situation.

As will be explained below, the value of water can sometimes be derived from the value of agricultural products for which water is an input in production. The market for farm products is considered the best example of pure competition in the United States. There is a large number of buyers and sellers for most crops, entry to the market is relatively easy, products are relatively homogeneous, and knowledge about prices and production is adequate. In addition, the products produced from farm products, including meat (through feedlot operations) and various vegetable food stuffs, are exchanged in competitive markets.

Valuation

Several examples of valuation are presented here. Most are for runoff in the Salt-Verde Basin, which contains nearly one half of the national forest land in Arizona and is the watershed which provides the surface water supply for much of the Salt River Valley around Phoenix. Runoff from the Basin is controlled by the Salt River Project, which manages six dams and reservoirs and distributes water through several canals to farms, businesses, and homes in the Valley. Four of the dams produce hydroelectric power. The Project also manages numerous wells which pump ground water to augment the surface supply.

Let us assume for these examples that an alternative is being considered for management of forest vegetation which would increase runoff from certain areas, that on-site runoff quantities with and without the alternative are known, and that actual runoff quantities made available for downstream uses are known. Further, assume that runoff quality does not change with the alternative (step 1).

In addition to instream use by fish, wildlife, and livestock, as well as by humans for recreation, the water is used to produce electricity and consumed by the

agricultural, municipal, and industrial sectors downstream (step 2). The value in electricity production and in final consumption will be derived here (step 3).

Value in Electricity Production

The cost savings method is well suited to this situation, because the additional runoff would, in the Salt-Verde Basin, replace power produced by a more expensive alternative (step 4). The Salt River Project produces power both from the hydroelectric dams it manages and from plants using both oil and coal as fuel. Oil and coal are sold competitively. The oil, despite its increasing cost, is important in handling peak demand periods. Power produced by the additional runoff could substitute for some of the power produced using oil, without affecting the total quantity of power produced. Figure 4 represents the savings assuming that 100,000 acre feet is the amount of the substitution only.

Based on an approximate 1977 oil price of \$15.00 per barrel, and other costs of power production, increased runoff would have the following values if it passed through the following dams⁷:

Hydroelectric dams	Value of an acre-foot of additional water
Theodore Roosevelt	\$4.50
Horse Mesa	6.00
Mormon Flat	3.00
Stewart Mountain	3.00

Thus, additional runoff flowing through all four dams has a 1977 gross value of \$16.50 per acre-foot.

Oil prices nearly doubled between 1977 and 1979, and there is considerable uncertainty about future fuel prices. If oil prices rise high enough, one of two outcomes is likely: either new fuel sources will be developed (coal gasification or oil from shale, for example) or power plants will be modified to utilize coal to handle short-term needs such as peak electricity demands. These alternatives all involve significant costs, suggesting that the real value of additional runoff in power production should rise above the 1977 estimate.

Value at Point of Consumption—A Cost Savings Approach

The Salt River Project pumps ground water from nearly 250 wells in order to supplement the surface runoff supply. Additional runoff would replace pumped water, thus reducing operation and maintenance costs for some wells and slowing the rate of ground water depletion, making future pumping less expensive (step 4). Water from the least efficient pumps would be

⁷Based on information provided by the Salt River Project, Phoenix, Arizona.

replaced first, so that the cost savings would decrease with increasing volumes of increased runoff. The estimated savings per acre foot for 1977 are:⁸

	Acre feet increment	Operation and maintenance	Reduction in groundwater depletion
1	25,000	\$20.00	\$1.60
2	25,000	16.50	1.53
3	25,000	16.00	1.44
4	25,000	14.30	1.37

Thus, the gross value of initial increases is estimated at \$21.60 per acre foot. As with the power production example, figure 4 represents the cost savings assuming the quantity 100,000 acre feet represents only the replacement.

Value at Point of Consumption—A Change in Net Income Approach

The primary users in the Salt River Valley of any additional water from the Salt-Verde Basin are farmers. There is some unmet demand for water to irrigate feed grain and forage crops. All other, higher valued demands are already met and are always able to bid water away from the lower valued uses.

Most agricultural products, and most variable inputs used in the production of agricultural products, are sold in relatively competitive markets. Thus, it is appropriate to derive the value of irrigation water from the value of farm products using the change in net income method (step 4).

This application of the change in net income method is complicated by the multiproduct nature of the affected farms. Most farms receiving runoff from the Salt-Verde Basin produce a range of crops, from vegetables to cotton to feed grains and alfalfa, in order of decreasing value per acre. The exact combination of crops grown, and the acreage in each crop, will depend on available acreage, water availability and price, production costs per crop, returns per crop, water use per crop, double cropping and crop rotation possibilities, and the risk aversion of the farmer. Thus it has been common to model representative farms and use linear programming to allocate acreages to different crops given constraints on all relevant variables (for examples, see Hartman and Whittelsey [n.d.] and Kelso et al., 1973).

Figure 10, which depicts supply and demand curves for crop irrigation water in the Salt River Project based on a representative farm of 1,000 acres, is a 1977 update of similar schedules developed by Kelso et al. (1973) for 1966.⁹ The supply schedule depicts the

⁸Based on data provided by the Salt River Project, Phoenix, Arizona.

⁹From a report to the USDA Forest Service by William E. Martin and Gary B. Snider of the University of Arizona, Department of Agricultural Economics, titled "Valuation of water and forage from the Salt-Verde Basin of Arizona," September 1979, available from the Rocky Mountain Forest and Range Experiment Station, Flagstaff, Arizona.

variable costs to the farmers of different quantities of water available to the total farm acreage in the Project area. The demand schedule depicts the return to water and all fixed costs for different crops, and the acreage of different crops assuming water prices as shown on the supply schedule. The costs, returns, and water savings for each crop are listed in table 4. For example, wheat returns \$24.03 per acre foot to water and fixed costs. If water cost rose to \$24.03, farmers could not afford to grow wheat, even in the short run.

The demand and supply schedules intersect at a vertical section of the demand schedule, where total water use is 549,198 acre feet. Theoretically, up to 62,905 (12,103 minus 549,198) acre feet of additional water would be used, if available, to irrigate additional acreage, with each acre foot yielding a return to water and fixed costs of about \$16.54.

As depicted in figure 10 by the horizontal segments of the supply curve, it is assumed that marginal and average variable costs of production are equal for each crop. Thus, the supply curve in figure 10 is that of the input water. The corresponding final product supply curve would also be horizontal over the relevant change in output, as is the supply curve for lumber in figure 5 for an increase from 5 to 6 MMBF.

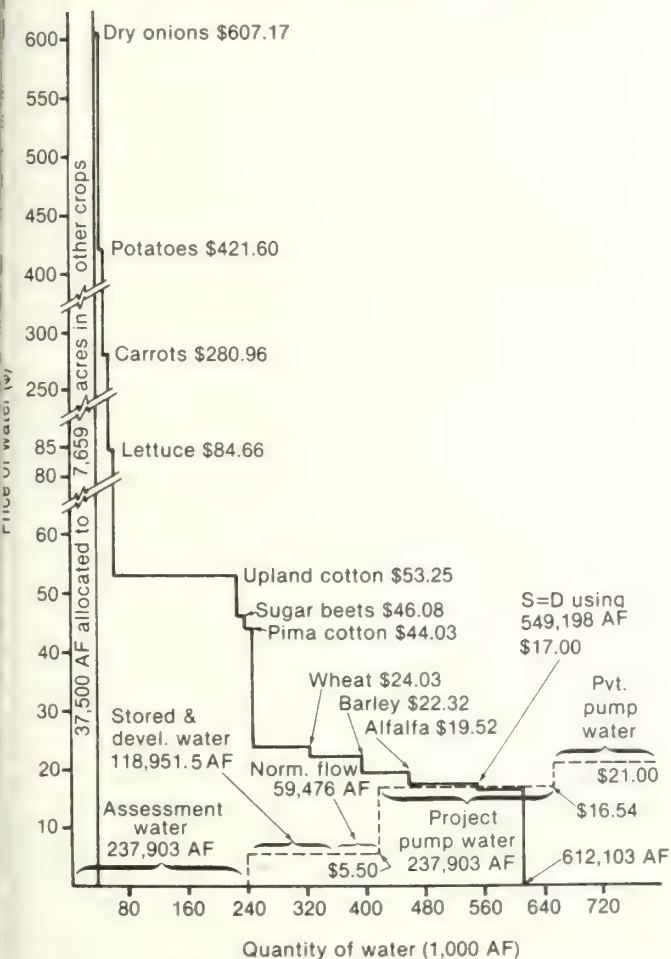


Figure 10.—Aggregate agricultural derived demand for and marginal supply of irrigation water, all farms, Salt River Project, 1977. From Martin and Snider's report "Valuation of water and storage from the Salt-Verde Basin of Arizona."

In reality, additional runoff would result in increased acreage planted only if the Salt River Project adjusted project pump water rates downward in response to the addition, or if all project pump water were replaced by runoff (essentially causing a drop in water rates for quantities above 420,000 acre feet). These two possibilities would each be depicted graphically by a new intersection of the demand and supply schedules in figure 10. However, such an outcome is unlikely for realistic increases. Nevertheless, the analysis depicted in figure 10 gives an approximation of the marginal value of water.

The modeling approach is very useful for estimating future values. Projections for the Salt River Project area⁹ were based on assumptions about increases in pumping depth, future SRP water prices to farmers, and agricultural crop acreage. Total agricultural acreage was assumed to decrease in the future at a rate of 3 percent per year, which is the average annual decrease since 1965. Maximum proportions of the total agricultural acreage assigned to each crop were based on historical proportions and information about crop rotation needs and farmer's aversion to risk.

The projections for 1977 to 2015 are that the marginal value of water to the farmers, in 1977 dollars, rises to \$19.20 in 1985, \$19.52 in 1995, and remains at about that level to at least 2015. By 1995, project pump water would no longer be used by farmers, assuming continuation of current supplies of surface water. The relatively low cost of surface water would allow continued growing of field crops such as wheat and barley, which would be grown to reduce risk and provide crop rotation benefit. All high valued crops, including cotton and sugar beets, would use about 60 percent of total agricultural water, compared with 44 percent in 1977. Of course, one must not place too much weight on such projections. The past may not be a good guide to future rates of agricultural land conversion to future crop patterns. If the marginal use of water runoff changed, the value would increase significantly.

Sophisticated models are useful in estimating water values, as stated above, where affected farms produce several crops with different values and water use efficiencies. However, an estimate of at least the current water value is generally possible without using such models. The analyst must merely decide which crop or crops are the marginal crops in terms of return to water and fixed costs. In the Salt River Project area the obvious candidates are alfalfa, sorghum, and maybe barley. The net return to water and fixed costs per acre foot of water used is estimated, as stated above, by subtracting variable costs minus water cost per acre from returns per acre, and then dividing the return per acre by the acre feet of water used per acre following a source of farm budgets such as that developed by Hathorn and Farr (1977) for Maricopa County, which includes the Salt River Project. The net returns for alfalfa, sorghum and barley are \$19.52, \$16.54, and \$22.31 per acre foot, respectively, in 1977 dollars (table 4). The marginal gross value of water may be assumed to be equal to the lowest of these — \$16.54 per acre foot.

Table 4.—Summary of yields, prices, water use, and net returns per acre used in the model¹

Crop	Unit	Yield	Price/Unit (\$)	Gross returns (\$)	Variable cost ² (\$)	Net returns (\$)	Acre-feet per acre	Net return per acre foot
Pima cotton lint	lbs.	600	.90	540.00	355.43	220.13	5.00	44.03
Seed	tons	1.046	68.00	35.56				
Upland cotton lint	lbs.	1,100	.52	572.00	366.99	266.26	5.00	53.25
Seed	tons	1.750	70.00	61.25				
Wheat	cwt.	42.5	5.00	212.50	140.40	72.10	3.00	24.03
Grain sorghum	cwt.	36.0	4.25	153.00	103.39	49.61	3.00	16.54
Barley	cwt.	37.0	5.00	185.00	125.42	59.58	2.67	22.31
Alfalfa	tons	6.6	65.00	429.00	306.98	122.02	6.25	19.52
Sugar beets	tons	24.5	24.00	588.00	357.32	230.38	5.00	46.08
Potatoes	cwt.	300	9.00	2,700.00	³ 1,435.25	1,264.75	3.00	421.58
Lettuce	cwt.	275	7.00	1,925.00	³ 1,655.70	269.30	3.50	76.94
Carrots	cwt.	225	8.50	1,912.50	³ 1,210.10	702.40	2.50	280.96
Dry onions	cwt.	425	8.25	3,506.25	³ 1,684.78	1,821.47	3.00	607.16

¹Adapted from Martin and Snider's report "Valuation of water and forage from the Salt-Verde Basin of Arizona."

²Source: Hathorn and Farr (1977), adjusted to exclude the cost of water, to exclude fixed costs, and to include 5% of total variable costs as miscellaneous variable business overhead costs as did Mack (1968).

³Current complete vegetable crop budgets are not available. Budgets for 1966 (Mack) were adjusted in proportion to the rise in costs for field crops between 1967 (Mack) and 1977 (Hathorn and Farr). Variable costs have risen by a factor of 2.5.

Another change in net income approach to valuing irrigation water, which applies where the change in water supply would cause changes in water use per acre rather than a change in acres irrigated, is to utilize irrigation water efficiency studies. Such studies show the change in yield per acre for different crops as more water is applied per acre while holding other inputs constant. The value of an additional irrigation is equal to the value of the increase in yield minus the costs of applying the additional irrigation (excepting the actual cost of the water).

Theoretically the rational farmer would use water in irrigating all crops so that the marginal values of water in irrigating each crop would be the same. However, various institutional and technical arrangements peculiar to the farming operation may preclude this. Thus, the analyst is wise to base such a valuation on examination of several crops.

Irrigation efficiency studies are not available for all crops in all locations, but such studies are available for some crops in major irrigation areas (see, for example, the bibliography in Anderson and Maass 1971). Crop response to irrigation is a matter of timing and quantity of irrigation water, as well as related timing and quantity of other inputs such as fertilizer. Some studies are more complete than others in their treatment of these relationships.

Ayer and Hoyt (1981) developed crop production functions for cotton, wheat, and sorghum on medium textured soils in Arizona, such as the Salt River Project area, based on several irrigation studies. Their production functions were sensitive to the quantities, but not the timing, of the inputs.

Use of their production functions to estimate the value of an additional acre inch of irrigation water, while holding all other variables at their mean levels, yielded a range of values.

For example, one additional acre inch of irrigation water, added to the 3 feet of water typically applied (table 4), on sorghum planted on medium textured soil will increase yields by about 30 pounds per acre. Based on our price of \$4.25 per cwt. (table 4), the gross value of the increase in production is \$15.30 per acre-foot. Subtracting the application (labor) cost of \$6.73 per acre foot (Hathorn and Farr 1977), yields a net of \$8.57 per acre-foot. For cotton and wheat, this approach yielded gross values of \$31 and \$0 per acre foot respectively.

Thus, use of this approach suggests that the marginal value of water in irrigating the lower-value crops (sorghum and wheat) is below \$9 per acre foot, considerably lower than the values derived using the other approaches, where the number of acres irrigated is not fixed. It is reasonable to expect the value of more water added to an already irrigated acre to be less than the value of water used to irrigate a previously unirrigated acre.

Comparing the four estimates of marginal gross water value at the points of consumption, the cost savings approach yielded a value of \$21.60 per acre foot. The two change in net income approaches based on increasing acreage per crop yielded a value of \$16.50 per acre foot. And the change in net income approach based on increasing water use per acre yielded a value below \$9 per acre foot.

Finally, what about future crop prices? Will real crop prices rise, causing real increases in residual water values, assuming the real costs of other inputs remain constant? In the absence of knowledge of the future, we can receive some guidance from past trends. Real prices of wheat and sorghum for grain have risen only slightly over the past century, and real prices of barley and hay have decreased slightly (Manthey 1977, table AP-5). Thus, the 1977 water value is a reasonable estimate of at least near future real values.

SUMMARY AND CONCLUSIONS

Monetary values can be useful measures of importance for public decision making. Where possible, monetary values are derived from market data. Such market-derived monetary values are a function of market institutions, externalities, advertising efforts, public good management decisions, the income distribution, and other factors which determine prices. The user of monetary values should be aware of the determinants of such values.

There is more than one monetary value for a given resource in a given situation. The correct derivation of monetary value depends on the use to which the value will be put. In land management planning, where decisions will be made about whether to change the quantity or quality of some product of the land, appropriate values are the changes in consumers' and producers' surplus.

Where the price of a product, needed in order to calculate the appropriate surplus measure, is not determined in a purely competitive market, techniques are sometimes available to estimate the price as if such a market existed. The most important prerequisites in estimating appropriate monetary values are an understanding of theoretical basis for the valuation and of the relevant markets. Often sufficient data or previous studies exist which, given these prerequisites, allow estimation of monetary values for land management planning in a relatively short time period. However, the user of such monetary values must be aware of the ever-present data problems associated with their estimation.

Additional problems arise in applying monetary values to management alternatives which span more than just the next few years. Two such problems are particularly important. First, future real prices are not known. Past changes in real prices may not be good indicators of future changes. Second, current prices, upon which estimates of surplus changes are based, are the result of innumerable private decisions made within the existing institutional framework of the economy. These prices are not necessarily appropriate weights for resource planning which affects future generations who have no say in today's market.

No matter how much effort goes into the valuation, it is usually best, and often necessary, to state a range for the required value, in addition to a best guess. This range should be used in the analysis of the land management alternatives. This is accomplished with sensitivity analyses to determine if the choice between alternatives depends on what value is chosen within the range. If it does, perhaps more effort is needed to more accurately specify the value.

Although using monetary values in public decision making has serious problems, it also has important benefits. The value of monetary values in decision making has been summarized well by Kenneth Boulding (1970, p. 129-130):

Even though economic measurement may be abused, its effect on the formation of moral judgements is great, and on the whole, I believe, beneficial... We can grant, of course, that the... dollar... is a

dangerously imperfect measure of the quality of human life and human values. Nevertheless, it is a useful first approximation, and when it comes to evaluating difficult choices it is extremely useful to have a first approximation that we can then modify. Without some guideline, indeed, all evaluation is random selection by wild hunches.

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This paper describes methods for deriving monetary values for three market products of the forest: timber, forage and water. Elements of the theory are reviewed and applied to actual forest conditions in central Arizona using available data. The paper should aid analysts with microeconomics training in understanding economic studies of resource values and in conducting valuations during the public land management planning process.

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Rocky
Mountains



Southwest



Great
Plains

U.S. Department of Agriculture
Forest Service

Rocky Mountain Forest and Range Experiment Station

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Research programs at the Rocky Mountain Station are coordinated with area universities and with other institutions. Many studies are conducted on a cooperative basis to accelerate solutions to problems involving range, water, wildlife and fish habitat, human and community development, timber, recreation, protection, and multiresource evaluation.

RESEARCH LOCATIONS

Research Work Units of the Rocky Mountain Station are operated in cooperation with universities in the following cities:

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Flagstaff, Arizona
Fort Collins, Colorado*
Laramie, Wyoming
Lincoln, Nebraska
Lubbock, Texas
Rapid City, South Dakota
Tempe, Arizona

*Station Headquarters: 240 W. Prospect St., Fort Collins, CO 80526

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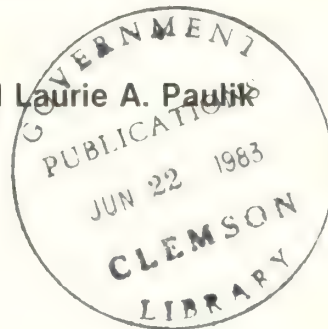
Fort Collins,
Colorado 80526

General Technical Report
RM-96



A Floristic Inventory of the Plant Communities of the San Francisco Peaks Research Natural Area

James M. Rominger and Laurie A. Paulik



Abstract

In this study area, covering 1,024 acres of alpine and subalpine vegetation on the west slopes of Humphreys Peak in Coconino County, Arizona, 129 species of vascular plants were found within nine plant communities or habitat types, as classified by Moir and Ludwig.

A Floristic Inventory of the Plant Communities of the San Francisco Peaks Research Natural Area¹

**James M. Rominger, Professor of Botany and
Curator of the Deaver Herbarium
and
Laurie A. Paulik, University Library Staff
Northern Arizona University²**

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²Flagstaff. Paulik was formerly a Technician at the Deaver Herbarium.

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A Floristic Inventory of the Plant Communities of the San Francisco Peaks Research Natural Area

James M. Rominger and Laurie A. Paulik

INTRODUCTION

The San Francisco Peaks Research Natural Area hereafter referred to as the SFPRNA or the Natural Area) was established in 1935. It reserves, for future study, representative alpine and subalpine communities in northern Arizona. One of the original criteria for selecting the present location of the SFPRNA was to protect a representative sample of bristlecone pines (*Pinus aristata*). These trees occur nowhere else in the state of Arizona except on the San Francisco Peaks. Within the Natural Area are nearly pure stands of Engelmann spruce (*Picea engelmannii*) and bristlecone pine, and a small portion of the only alpine tundra in Arizona. This study defines the plant communities within the Natural Area and includes a checklist of the vascular plants growing within its boundaries (appendix A). This will provide baseline information for all future research done on the San Francisco Peaks Research Natural Area.

The first biological survey party to traverse the Natural Area was headed by C. Hart Merriam (1890), who collected the biota of the San Francisco Peaks during the summer of 1889. His base camp was at Little Springs, which lies about 1.5 miles northwest of the SFPRNA. Between 1937-39, E. L. Little (1941) collected extensively in the alpine tundra of the San Francisco Peaks reporting 49 alpine species. Moore (1965) added two species to the known alpine flora, and Schaack (1970) expanded the number of known species of the alpine tundra to a total of 82. Paulik (1979) reported 189 species of vascular plants for the subalpine spruce-fir forest complex of the San Francisco Peaks. And, the San Francisco Peaks were included by Moir and Ludwig (1979) in their classification of habitat types of the spruce-fir and mixed coniferous forests.

STUDY AREA

The SFPRNA is on the west slope of Humphreys Peak about 15 miles (24 km) north of Flagstaff, Arizona. The site (fig. 1), which includes one whole section and nearly two-thirds of another, covers 1,024 acres.³ The southern edge of the Natural Area is 0.8 miles north and 0.2 miles east of the Arizona Snow Bowl. It replaces an earlier Natural Area that was adjacent to the Arizona Snow Bowl. In 1966, that portion of the Natural Area located in Section 31, was deleted and a portion in Section 19 was added. Section 30 has remained intact since 1935.

³SFPRNA covers section 30 and two-thirds of section 19 in Township 23N, Range 7E.

Elevation ranges from 9,100 feet (2,800 m) at the northwest corner to about 12,100 feet (3,700 m) at the southeast corner. The site is characterized by steep, mountainous terrain, including several parallel canyons and talus slopes which drain westward toward the Bismarck Lake area (fig. 2). Two unmarked but well-worn foot trails traverse the SFPRNA, each leading towards Humphreys Peak in a meandering southeasterly direction. Two abandoned 4-inch pipelines are still intact in lower White Horse Canyon and in the two adjacent canyons to the south. These pipelines, which were installed in the late 1940's to carry water to livestock on private lands northwest of the SFPRNA, connect with springs in the alpine tundra below Humphreys Peak (fig. 3). Their removal would be impractical and would cause unnecessary damage to the terrain.

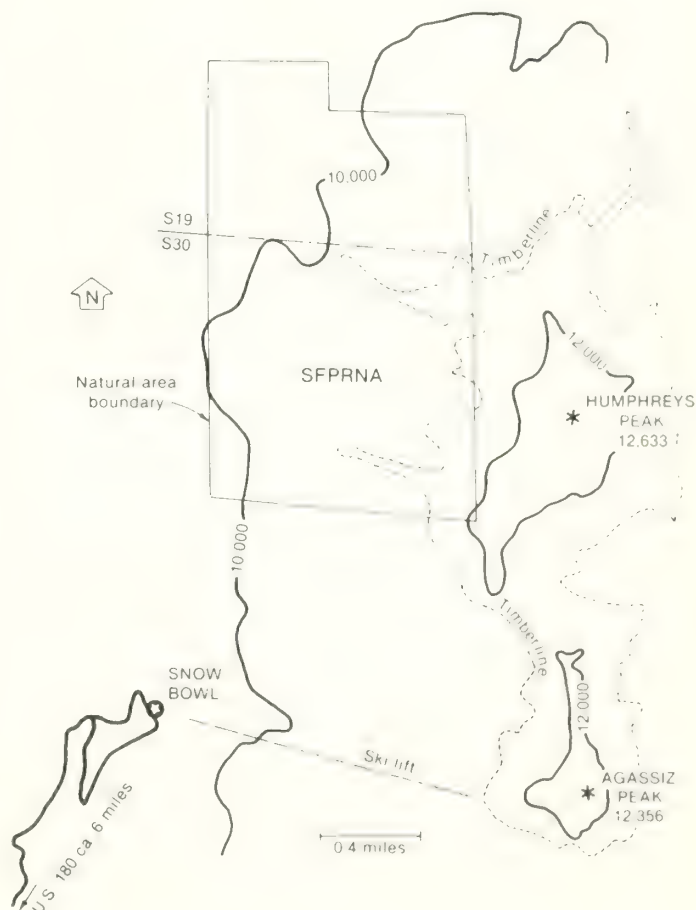


Figure 1.—Sketch map of the San Francisco Peaks Research Natural Area.



Figure 2.—View of the SFRNA from Forest Service Road 418 in the fall.



Figure 3.—Closeup of four-inch pipeline in the White Horse Canyon.

METHODS

Eleven collecting trips were made into the SFRNA during the growing season of 1980.⁴ These included one trip in June, four in July, four in August, and two in September. Snow covered much of the area above 11,000 feet until after mid-July.⁴ Field notes were recorded for each trip, and voucher specimens were filed at the Deaver Herbarium, Northern Arizona University, Flagstaff. Attempts were made to correlate field observations with habitat type (HT) descriptions of Moir and Ludwig (1979) for the San Francisco Peaks. Visual stem counts were made in mixed conifer and spruce-fir communities at elevational intervals of about 200 feet (60 m) to determine dominance. Notes were kept to indicate approximate elevation and slope exposure where one dominant species was replaced by another.

⁴Equipment carried on each trip included compass, altimeter, Humphreys Peak Topographical Quadrangle map, aerial photos of the area, camera, trowel, and plant collecting bags.

Aerial photographs taken of the area in 1967 were enlarged (to the scale of 8 inches = 1 mile) and used in the preparation of the vegetation map. The boundaries of both aspen and alpine tundra communities were determined from these.

RESULTS AND DISCUSSION

The major portion of the SFRNA is covered by a mixture of Engelmann spruce and corkbark fir (*Abies lasiocarpa* var. *arizonica*), but there are also significant stands of bristlecone pine and aspen (*Populus tremuloides*), as well as a small area of alpine tundra.

Field studies in this area resulted in the collection of 129 species from 89 genera and 43 families of vascular plants. In her thesis study of the previous year, Paulik (1979) reported 189 species for the subalpine as a whole. There are several reasons for the smaller number of species found in the Natural Area: (a) the area is much smaller, with some habitats greatly reduced; (b) no part of the Inner Basin, which has several species unique to it, is within the Natural Area; and (c) of the 189 species previously collected, 17% or 33 species were considered weedy or introduced and were found primarily around the Arizona Snow Bowl lodge or along hiking trails. Disturbances of this kind occur much less frequently in the Natural Area, and thus few weedy species were recorded.

The plant collections also produced four previously unreported records for the San Francisco Peaks. Timber oatgrass (*Danthonia intermedia*) was formerly reported only from the White Mountains and the Mogollon Rim in wet meadows and pine forests (McDougall 1973). Mountain trisetum (*Trisetum montanum*) was known only from Apache County. Whortleberry (*Vaccinium oreophilum*) was known only from the White Mountains. Now, all three can be included in the San Francisco Peaks flora. Over's goosefoot (*Chenopodium overi*) appears to be an introduced species not previously reported for the subalpine zone of the Peaks.

The presence or absence of the proposed endangered species reported for the area was also noted. The subalpine buttercup (*Ranunculus inamoenus* var. *subaffinis*) is fairly common in moist to mesic meadows throughout the Natural Area. The alpine groundsel (*Senecio franciscanus*) though not as common as the buttercup, was not difficult to find on the gravelly talus slopes of the alpine and upper subalpine area.

Based on plant collections, field observations, and literature studied, nine plant communities are recognized within the boundaries of the SFRNA. These are described in some detail below and are outlined on a vegetation map in appendix II. The communities are named for the dominant plants in each and are based on Moir and Ludwig's (1979) habitat type studies, indicated by HT, and the vegetation classification system of Brown et al. (1979).

In the description of the plant communities, common names and/or acronyms are sometimes used for con-

enience. The major trees and dominant herbs for which the plant communities are named are listed in table 1.

Table 1.—Scientific name, acronym, and common name of the major trees and dominant herbs of the nine plant communities of the SFPRNA

Scientific name	Acronym	Common name
<i>Picea engelmannii</i>	PIEN	Engelmann spruce
<i>Abies lasiocarpa</i> var. <i>arizonica</i>	ABLA	Corkbark fir
<i>Populus tremuloides</i>	POTR	Aspen
<i>Pinus aristata</i>	PIAR	Bristlecone pine
<i>Geum rossii</i> var. <i>turbinatum</i>	GERO	Mountain avens
<i>Lupinus parryi</i>	PRPA	Parry's primrose
<i>Carex bella</i>	CABE	Beautiful sedge
<i>Muhlenbergia montana</i>	MUMO	Mountain muhly
<i>Lathyrus arizonicus</i>	LAAR	Arizona peavine
<i>Eriogonum superbus</i>	ERSU	Showy fleabane

Plant Communities

1. *Picea engelmannii*/Moss (PIEN/MOSS) HT

This HT, covering over 400 acres, ranges from 10,000 to 11,000 feet and dominates the west-facing slopes at the upper middle elevations (fig. 4). Engelmann spruce are largest in diameter (d.b.h.) and outnumber corkbark fir by at least three to one. The understory varies according to available light, with Arizona peavine (*Lathyrus arizonicus*) prevailing in forest openings. Under a closed canopy, which typifies this HT, herbaceous vegetation is sparse, with mosses and lichens providing most cover (fig. 5). The herbs seen most frequently are wild strawberry (*Fragaria ovalis*), fireweed (*Epilobium angustifolium*), mountain parsley (*Pseudocymopterus montanus*), orange sneezeweed (*Helenium hoopesii*), and green gentian (*Swertia radiata*). Predominant shrubs are gooseberry current (*Ribes montigenum*), orange gooseberry (*Ribes pinetorum*), and bearberry honeysuckle (*Lonicera involucrata*). Below 10,000 feet, Engelmann spruce begins to give way to corkbark fir, the codominant tree which is present throughout the HT. On higher and wetter sites, the PIEN/GERO HT replaces it. Below, it merges into the ABLA/LAAR HT. Occasionally limber pine (*Pinus flexilis*) is encountered on exposed ridges.

2. *Picea engelmannii*/*Geum rossii* (PIEN/GERO) HT

On wetter, north-facing slopes, this HT dominates. Its elevation is generally higher than PIEN/MOSS HT, ranging from 10,500 to 11,500 feet. This HT contains nearly pure stands of Engelmann spruce with occasional corkbark fir. The soil is moist and snow covered until early July. The herbaceous cover is dominated by mountain avens (*Geum rossii*)⁵ in association with a variety of species also found in the adjacent alpine tundra,

⁵Mountain avens is correctly named *Geum rossii* (R. Br.) Ser. var. *turbinatum* (Rydb.) C. L. Hitchc., (Lehr and Pinkava 1980), and is the equivalent of *Geum turbinatum* Rydb. as treated by McDougall (1973), Kearney and Peebles (1960) and Lehr (1978).



Figure 4.—*Picea engelmannii*/Moss HT at about 10,500 feet.



Figure 5.—Closeup of *Picea engelmannii*/Moss HT.

including Jacob's ladder (*Polemonium delicatum*), franciscan bluebells (*Mertensia franciscana*), golden columbine (*Aquilegia chrysantha*), and alpine fescue (*Festuca ovina* var. *brachyphylla*).

3. *Abies lasiocarpa*/*Lathyrus arizonicus* (ABLA/LAAR) HT

On west-facing slopes at lower elevations, this HT dominates. Ranging from 9,500 to 10,000 feet, it is the dominant HT where the road from Bismarck Lake enters the forest. In the SFPRNA, perhaps one-third of this HT is in a seral stage dominated by aspen, particularly in Section 19. Corkbark fir outnumbers Engelmann spruce by about five to one, but a few large, mature spruce are present. The understory is dominated by Arizona peavine in the openings, with a sparse scattering of the following herbs: Richardson's geranium (*Geranium richardsonii*), starflower (*Smilacina stellata*), wintergreen (*Pyrola* spp.), spotted coral root (*Corallorhiza maculata*), meadow rue (*Thalictrum fendleri*), creeping barberry (*Berberis repens*), and fringed brome (*Bromus richardsonii*).

4. *Abies lasiocarpa*/*Erigeron suberbus* (ABLA/ERSU) HT

In the northwest corner, the terrain is interspersed with several shallow canyons paralleling White Horse Canyon, all of which slope abruptly to the northwest. In this area, Douglas-fir (*Pseudotsuga menziesii*) makes its only appearance in the SFPRNA. It is the largest tree in this community, but corkbark fir is greatest in density. Douglas-fir may represent a seral stage that is gradually being replaced by corkbark fir. Douglas-fir is most abundant on south-facing slopes at elevations below 9,400 feet. Limber pine and corkbark fir are present on west-facing slopes, and Engelmann spruce becomes a major component on north-facing slopes. White fir (*Abies concolor*), which is a frequent inhabitant of such a mixed coniferous forest in Arizona, is notably absent. Understory vegetation is a mixture of showy fleabane (*Erigeron superbus*), wintergreen, starflower, creeping barberry, Richardson's geranium, Canadian violet (*Viola canadensis*), sweet cicely (*Osmorhiza depauperata*), and fairybells (*Disporum trachycarpum*). Several interesting shrubs are found on the north side of White Horse Canyon; these include Scouler's willow (*Salix scouleri*), service berry (*Amelanchier utahensis*), mountain ash (*Sorbus dumosa*), and rock spiraea (*Holodiscus dumosus*). The only collection of whortleberry was made at 9,500 feet in White Horse Canyon.

5. *Pinus aristata* community

This bristlecone pine community is found on south-facing ridges and talus slope edges at elevations between 10,500 and 11,500 feet (fig. 6). Occasionally Engelmann spruce and limber pine are intermixed. Except for sporadic shrub cover of common juniper (*Juniperus communis*) and gooseberry currant, there is a very sparse understory. The few herbs present are wild candytuft (*Thlaspi fendleri*), yellow draba (*Draba aurea*), Whipple's beardtongue (*Penstemon whippleanus*), and alpine fescue. The bristlecone pines are widely spaced and stunted at higher elevations. This community repeatedly appears on the north edges of talus slopes, which are the warmer and drier sites.

6. *Populus tremuloides* subclimax community

Extensive stands of aspen are found within the ABLA/LAAR HT, and a few arms extend upward into the PIEN/MOSS HT (fig. 7). These are seral stages, presumably following fire. Herbaceous cover varies greatly in response to the percentage of canopy cover. Under a relatively open canopy, Arizona peavine forms a luxuriant growth with a mixture of silvery lupine (*Lupinus argenteus*), American vetch (*Vicia americana*), Parry goldenweed (*Haplopappus parryi*), squirreltail (*Sitanion longifolium*), and fringed brome. Under a more closed canopy, such mesic species as starflower, creeping barberry, wintergreen, and baneberry (*Actaea arguta*) are found. Comparison of 1980

field observations of the aspen stands (taken from both Kendrick Park and Kendrick Mountain) with 1967 aerial photographs showed a decline in size of the aspen communities. Direct observation, on the ground, indicated very good regeneration of corkbark fir and Engelmann spruce beneath the aspen. Assuming no new fire damage occurs, these aspen communities may be replaced within the next 50 years. Depending on altitude and slope exposure, the true climax will be either Engelmann spruce or corkbark fir.

7. *Geum rossii*/*Carex bella* community

True alpine tundra is found in the southeast corner and extends downward on the exposed talus slopes in Section 30 (fig. 8). A small patch of tundra is also found on the exposed talus slope in the southeastern part of Section 19. This community is found mostly above 11,000 feet. It is dominated by mountain avens with a mixture of sedges, the most prevalent being the beautiful sedge (*Carex bella*). Other components of this community are sticky Jacob's ladder (*Polemonium viscosum*), moss campion (*Silene acaulis*), mountain sorrel (*Oxyria digyna*), painted alumroot (*Heuchera versicolor*), alpine groundsel, queen's crown (*Sedum rhodanthum*), spike trisetum (*Trisetum spicatum*), and spreading wheatgrass (*Agropyron scribneri*). At the lower extremes of the talus slopes in Section 30, a more dense shrub cover appears. This shrubby cover includes common juniper, gooseberry currant, red elderberry (*Sambucus microbotrys*), and bearberry honey-suckle.

8. *Primula parryi* community

This Parry's primrose community (fig. 9), recognized by Paulik (1979), covers less than 0.1% of the Natural Area and is restricted to high altitude regions which have additional moisture from seeps or springs. Parry's primrose dominates in abundance, size, and aroma. One such area is found at the eastern edge of Section 19 in a narrow vertical strip of about 200 feet. Associated with this community are such rare species as nodding bluegrass (*Poa reflexa*) and pygmy saxifrage (*Saxifraga debilis*). Other more ubiquitous herbs are mountain avens, Franciscan bluebells, subalpine buttercup and several sedges (*Carex* spp.). An abundant nurse crop of Engelmann spruce thrives here.

9. *Muhlenbergia montana*/forb meadow community

In the southwest corner at the lower end of the talus slope, there are a few grassy openings on southwest facing slopes adjacent to an aspen stand. These meadows are dominated by mountain muhly (*Muhlenbergia montana*) mixed with forbs and grasses typically found in the Douglas-fir and ponderosa pine communities of lower elevation. Associated grasses include Arizona fescue (*Festuca arizonica*), pine dropseed (*Blepharoneuron tricholepis*), and squirreltail. Common forbs are American vetch and silvery lupine. This is the



Figure 6.—*Pinus aristata* community at about 11,500 feet.



Figure 8.—*Geum rossii*/*Carex bella* community, with pipeline running through it.



Figure 7.—View of White Horse Canyon and *Populus tremuloides* subclimax community.



Figure 9.—*Primula parryi* community.

Table 2.—Plant communities of the SFPRNA, their equivalent association designation by Brown et al. (1979), and area (acres) covered

Map number	Plant community	Equivalent from Brown et al. (1979)	Total area covered	Percent of total
1.	<i>Picea engelmannii</i> /Moss HT	121.311 <i>Picea engelmannii</i> - <i>Abies lasiocarpa</i> association	412	40.2
2.	<i>Picea engelmannii</i> / <i>Geum rossii</i> HT	121.312 <i>Picea engelmannii</i> assoc.	173	16.9
3.	<i>Abies lasiocarpa</i> / <i>Lathyrus arizonicus</i> HT	121.314 <i>Abies lasiocarpa arizonica</i> association	164	16.0
4.	<i>Abies lasiocarpa</i> / <i>Erigeron superbis</i> HT	121.314 <i>Abies lasiocarpa</i> 51 <i>arizonica</i> association		5.0
5.	<i>Pinus aristata</i> community	121.322 <i>Pinus aristata</i> assoc.	56	5.5
6.	<i>Populus tremuloides</i> subclimax community	121.316 <i>Populus tremuloides</i> subclimax association	82	8.0
7.	<i>Geum rossii</i> / <i>Carex bella</i> community	111.532 <i>Geum turbinatum</i> - <i>Carex bella</i> association	74	7.2
8.	<i>Primula parryi</i> community	111.052 Mixed Herb Series of Rocky Mt. Alpine Tundra	1	0.1
9.	<i>Muhlenbergia montana</i> forb meadow community	142.411 Mixed forb-grass assoc. of Rocky Mt. Montane grassland	1	.1
	Bare rock		10	1.0

only place in the SFPRNA that showed evidence of domestic livestock intrusion. A spring here is responsible for attracting cattle to this lush, grassy meadow at about 10,000 feet.

SUMMATION

Table 2 matches the plant community name used above with the corresponding association designation used by Brown et al. (1979); it also shows the amount of land area covered by the nine plant communities recognized.

Of the nine plant communities represented in the SFPRNA, the PIEN/MOSS HT is by far the most extensive. Second in size and sharing nearly equal acreage are the PIEN/GERO HT and the ABLA/LAAR HT. A casual visit to the SFPRNA gives the impression that the ABLA/LAAR HT is much more extensive than it actually is, as it lies along most of the western edge and must be passed through to reach other communities. The two smallest communities are the *Primula parryi* community and the *Muhlenbergia montana*/forb meadow community. Two communities which are particularly unique in Arizona are the *Pinus aristata* community (bristlecone pine) and the *Geum rossii*/*Carex bella* community (alpine tundra). These two communities are found nowhere else in the state of Arizona except on the San Francisco Peaks.

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APPENDIX A

Checklist of the Vascular Plants of the San Francisco Peaks Research Natural Area⁶

7. POLYPODIACEAE

Cystopteris fragilis (L.) Bernh. var. *tenuifolia*
(Clute) Brown

3. PINACEAE

Abies lasiocarpa (Hook.) Nutt. var. *arizonica*
(Merriam) Lemmon
Picea engelmannii Parry
Pinus aristata Engelm.
Pinus flexilis James
Pseudotsuga menziesii (Mirb.) Franco var.
glauca (Beissn.) Franco

9. CUPRESSACEAE

Juniperus communis L. var. *saxatilis* Pall. =
(var. *depressa* Pursh)

3. POACEAE

Agropyron scribneri Vasey
A. trachycaulum (Link) Malte var. *glaucom* (Pease
and Moore) Malte
A. trachycaulum (Link) Malte var. *latiglume*
(Scribn. & Smith) Beetle
Agrostis exarata Trin.
Blepharoneuron tricholepis (Torr.) Nash
Bromus frondosus (Shear.) Woot. & Standl.
B. richardsonii Link
Danthonia intermedia Vasey
Festuca arizonica Vasey
F. ovina L.
F. ovina L. var. *brachyphylla* (Schult.) Piper
F. sororia Piper
Koeleria cristata (L.) Pers. = (*K. pyramidata* (Lam.)
Beauv.)
Muhlenbergia montana (Nutt.) Hitchc.
Phleum alpinum L.
Poa fendleriana (Steud.) Vasey
P. interior Rydb.
P. pratensis L.
P. reflexa Vasey & Scribn.
P. rupicola Nash
Sitanion longifolium J. G. Smith
Trisetum montanum Vasey
T. spicatum (L.) Richt.

9. CYPERACEAE

Carex albonigra MacKenzie
C. bella Bailey
C. chalciolepis Holm
C. ebenea Rydb.
C. occidentalis Bailey
C. rossii Boott
C. siccata Dewey
C. wootonii MacKenzie

26. JUNCACEAE

Luzula parviflora Desv.
L. spicata (L.) DC.

27. LILIACEAE

Disporum trachycarpum (Wats.) Benth. & Hook.
Smilacina stellata (L.) Desf.
Zigadenus elegans Pursh

30. ORCHIDACEAE

Corallorhiza maculata Raf.
Goodyera oblongifolia Raf.

32. SALICACEAE

Populus tremuloides Michx.
Salix scouleriana Barratt

43. POLYGONACEAE

Oxyria digyna (L.) Hill

44. CHENOPODIACEAE

Chenopodium berlandieri Moq.
C. overi Aellen

50. CARYOPHYLLACEAE

Arenaria lanuginosa (Michx.) Rohrb. ssp.
saxosa (Gray) Mag.
A. obtusiloba (Rydb.) Fern.
A. rubella (Wahlenb.) J. E. Smith
Cerastium beeringianum Cham. & Schlecht.
Silene acaulis L. ssp. *subcaulescens* (F. N.
Williams) Hitchc. & Maguire
S. scouleri Hook. ssp. *pringlei* (Wats.) Hitchc. &
Maguire
Stellaria umbellata Turcz.

52. RANUNCULACEAE

Actaea arguta Nutt.
Anemone globosa Nutt.
Aquilegia chrysantha Gray
Ranunculus inamoenus Greene var. *subaffinis*
(Gray) L. Benson

53. BERBERIDACEAE

Berberis repens Lindl.

56. CRUCIFERAE

Draba aurea Vahl
D. crassifolia Graham
Thlaspi fendleri Gray

59. CRASSULACEAE

Sedum rhodanthum Gray

60. SAXIFRAGACEAE

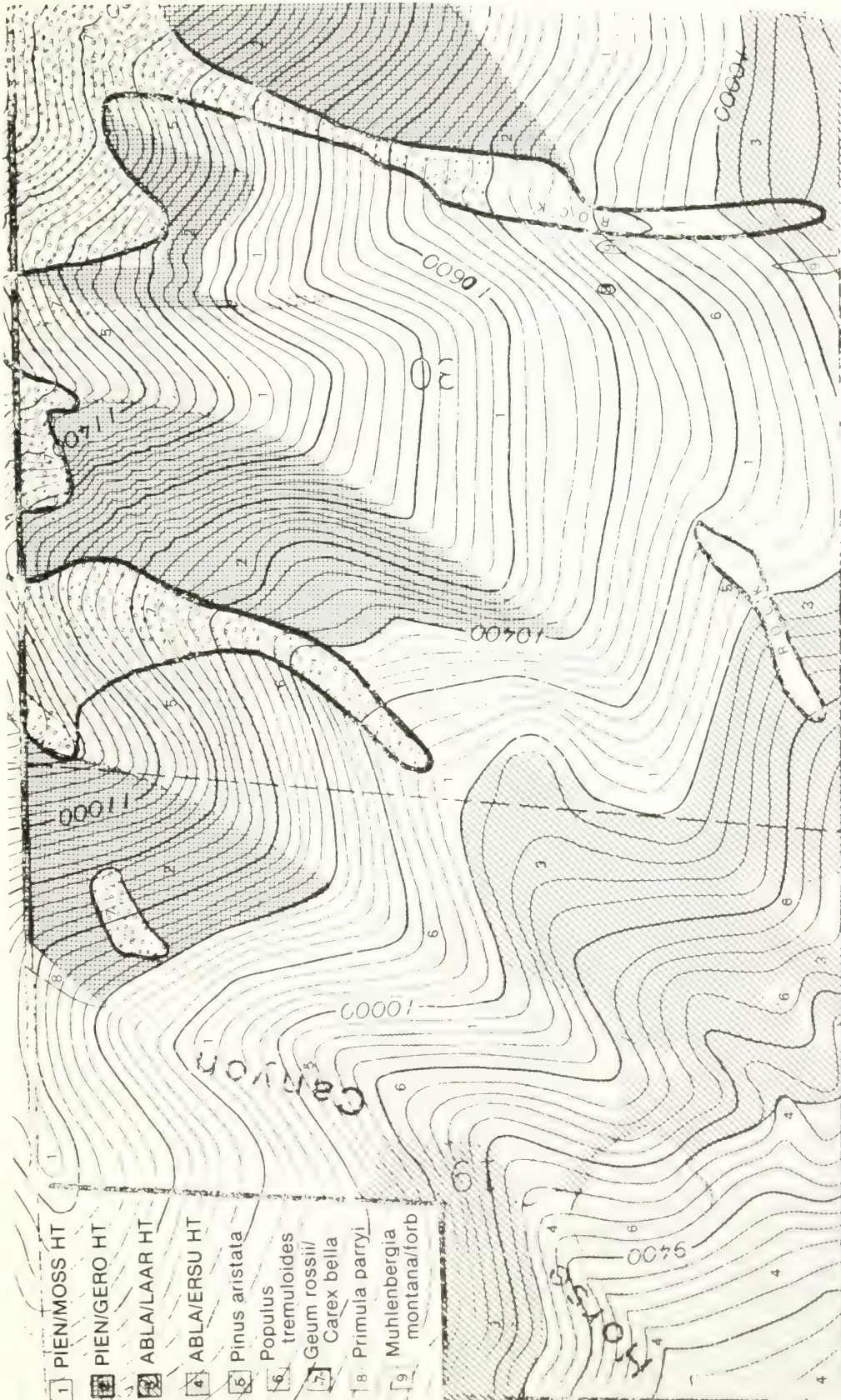
Heuchera versicolor Greene forma *pumila*
Rosendahl et al.
Ribes montigenum McClatchie
R. pinetorum Greene
Saxifraga debilis Engelm.
S. rhomboidea Greene var. *franciscana* (Small)
K. & P.

⁶Numbering and sequence of plant families follows McDougall
973) and Kearney and Peebles (1960).

63. ROSACEAE
Amelanchier utahensis Koehne
Fragaria ovalis (Lehm.) Rydb.
Geum rossii (R. Br.) Ser. var. *turbinatum* (Rydb.)
C. L. Hitchc.
Holodiscus dumosus (Nutt.) Heller
Potentilla diversifolia Lehm.
P. hippiana Lehm.
P. sibbaldii Hall. f.
Rubus strigosus Michx.
Sorbus dumosa Greene
64. LEGUMINOSAE
Lathyrus arizonicus Britton
Lupinus argenteus Pursh
Vicia americana Muhl.
65. GERANIACEAE
Geranium richardsonii Fisch. & Trautv.
74. EUPHORBIACEAE
Euphorbia lurida Engelm.
91. VIOLACEAE
Viola canadensis L.
97. ONAGRACEAE
Epilobium angustifolium L.
100. UMBELLIFERAE
Osmorhiza depauperata Phil.
Pseudocymopterus montanus (Gray) Coult. & Rose
103. ERICACEAE
Moneses uniflora (L.) Gray
Pyrola secunda L.
P. virens Schweigg.
Vaccinium oreophilum Rydb.
104. PRIMULACEAE
Androsace septentrionalis L.
Primula parryi Gray
110. GENTIANACEAE
Gentianella amarella (L.) Börner
G. barbellata (Engelm.) J. M. Gillett
Swertia radiata (Kellogg) Kuntze
114. POLEMONIACEAE
Polemonium delicatum Rydb.
P. viscosum Nutt.
116. BORAGINACEAE
Mertensia franciscana Heller
118. LABIATAE
Agastache pallidiflora (Heller) Rydb.
Monardella odoratissima Benth.
120. SCROPHULARIACEAE
Castilleja austromontana Standl. & Blumer
Pedicularis parryi Gray
Penstemon barbatus (Cav.) Roth
P. whippleanus Gray
Veronica wormskjoldii Roem. & Schult.
128. CAPRIFOLIACEAE
Lonicera arizonica Rehder
L. involucrata (Richards) Banks
Sambucus microbotrys Rydb.
Symphoricarpos parishii Rydb.
129. VALERIANACEAE
Valeriana acutiloba Rydb.
132. COMPOSITAE
Achillea lanulosa Nutt.
Agoseris arizonica Greene
A. aurantiaca (Hook.) Greene
Antennaria parvifolia Nutt.
A. umbrinella Rydb.
Erigeron flagellaris Gray
E. formosissimus Greene
E. simplex Greene
E. superbus Greene
Haplopappus parryi Gray
Helenium hoopesii Gray
Helianthella quinquenervis (Hook.) Gray
Senecio bigelovii Gray
S. franciscanus Greene
S. macdougallii Heller
Solidago decumbens Greene
S. multiradiata Ait.
Taraxacum officinale Weber

APPENDIX B

Vegetation Map of the San Francisco Peaks Research Natural Area





Rominger, James M., and Laurie A. Paulik. 1983. A floristic inventory of the plant communities of the San Francisco Peaks Research Natural Area. USDA Forest Service General Technical Report RM-96, 9 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

In this study area, covering 1,024 acres of alpine and subalpine vegetation on the west slopes of Humphreys Peak in Coconino County, Arizona, 129 species of vascular plants were found within nine plant communities or habitat types, as classified by Moir and Ludwig.

Keywords: Floristic inventory, research natural area, alpine vegetation, subalpine vegetation

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Rocky
Mountains



Southwest



Great
Plains

U.S. Department of Agriculture
Forest Service

Rocky Mountain Forest and Range Experiment Station

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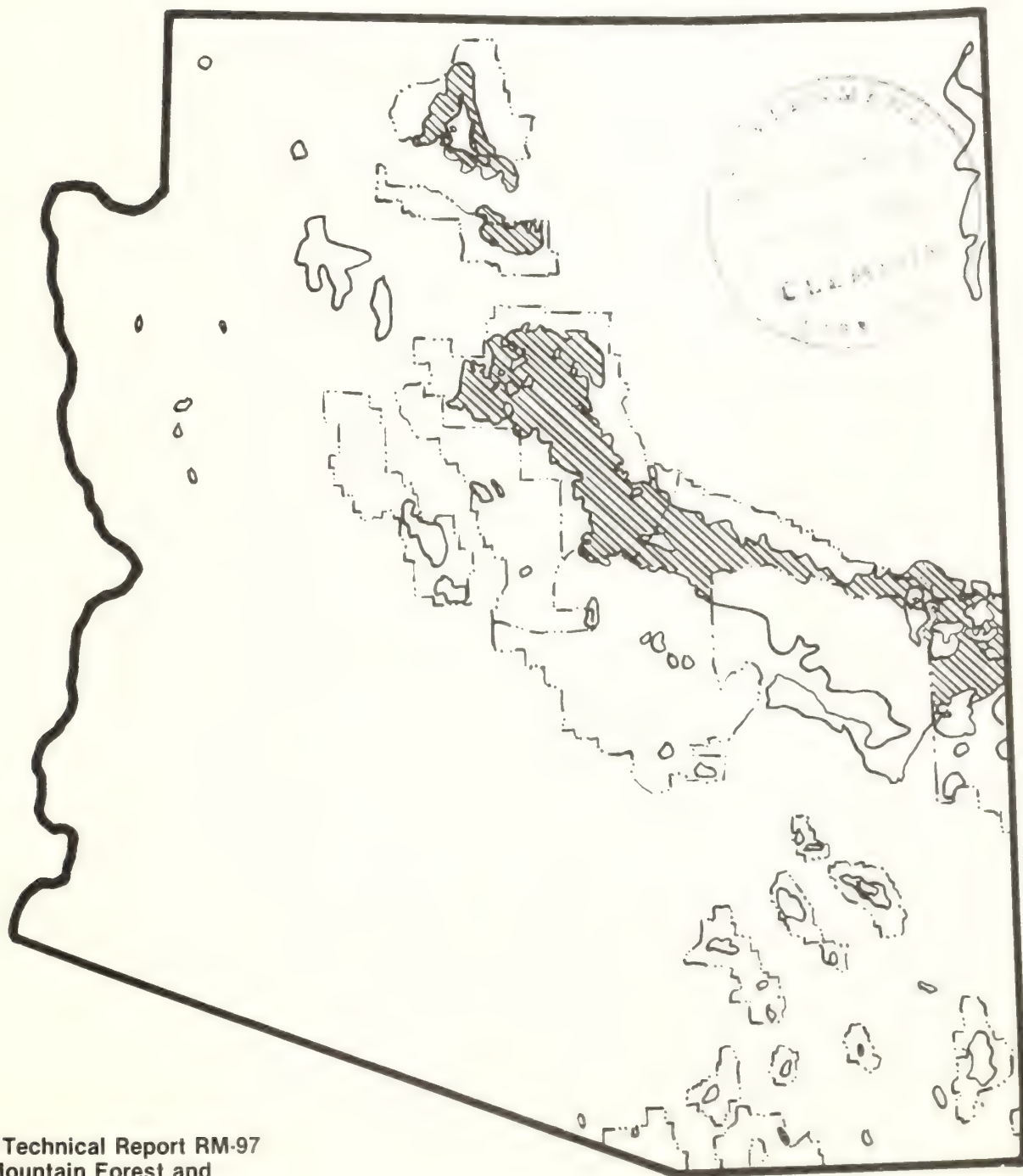
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A Habitat Type Classification System for Ponderosa Pine Forests of Northern Arizona

Jess P. Hanks, E. Lee Fitzhugh, and Sharon R. Hanks



Abstract

Four major habitat types (HT's), divided into 12 phases (P's), are described for the ponderosa pine forests of northern Arizona. In addition, five community types (CT's) are described for the same area. On a wet to dry gradient, the HT's are (1) *Pinus ponderosa*/*Muhlenbergia virescens*, (2) *Pinus ponderosa*/*Muhlenbergia virescens*-*Festuca arizonica*, (3) *Pinus ponderosa*/*Festuca arizonica*, and (4) *Pinus ponderosa*/*Bouteloua gracilis*.

Acknowledgments

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A Habitat Type Classification System for Ponderosa Pine Forests of Northern Arizona¹

**Jess P. Hanks, Associate Professor
Department of Biology, The City College of New York**

**E. Lee Fitzhugh, Extension Wildlife Specialist
Cooperative Extension, University of California, Davis²**

and

**Sharon R. Hanks, Associate Professor
Department of Biology, William Paterson College**

¹*This work was performed in cooperation with the USDA Forest Service, Southwestern Region, Albuquerque, New Mexico, and Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado.*

²*Work done while at Northern Arizona University, Flagstaff.*

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A Habitat Type Classification System for Ponderosa Pine Forests of Northern Arizona

Jess P. Hanks, E. Lee Fitzhugh, and Sharon R. Hanks

INTRODUCTION

Classification of ponderosa pine (*Pinus ponderosa scopulorum*) forests into habitat types can help improve understanding of the ecology of forested lands in the Southwest.

The study objective was to develop a classification and a key to identify the potential of land to support plant associations in ponderosa pine forests in northern Arizona. Ecotones between ponderosa pine, mixed conifer, and pinyon-juniper forests were sampled to provide a transition with Moir and Ludwig's (1979) classification of spruce-fir and mixed conifer forests in the same area, and with future work in pinyon-juniper areas.

The methodology was developed by Daubenmire and Daubenmire (1968) and modified by Franklin et al. (1970) and Pfister and Arno (1980). The classification can be used as the vegetation component of the "Modified Ecoclass" land classification system being developed by the USDA Forest Service (Buttery 1978).



Figure 1.—Distribution of *Pinus ponderosa* in Arizona. The study area, which is diagonal-striped, is restricted to ponderosa pine forests on the Colorado Plateau.

STUDY AREA

The study area encompassed northern Arizona (fig. 1). Spencer (1966) indicated that there are 3.36 million acres of commercial ponderosa pine forest in Arizona, much of which is included in the study. Forests ranged from 33.5 to 36.5 degrees latitude and from 109 to 112.5 degrees longitude, with only two breaks in continuity at the northwest end. The Kaibab plateau, which is isolated from the remainder of the study area, is split into two parts by the Grand Canyon. The north rim of the Canyon contains more than 1,000 square miles of forest, much of which is ponderosa pine. It is one of the few block plateaus that is bounded on all sides by escarpments and slopes which descend to lower vegetation types (Rasmussen 1941). The influence of Great Basin vegetation and climate are pronounced on these two areas, leading one to expect different plant communities than elsewhere in the study area.

Elevation ranges from about 6,000 to 9,000 feet (1,830 m to 2,740 m). Soils are derived from igneous, alluvial, and sedimentary parent materials. Cold winters and cool summers are characteristic. Precipitation is nearly equally divided between snowfall from November through March and convective rainstorms during July and August. Rainfall tends to predominate in the southeast and snowfall in the northwest parts of the area. An apparent moisture gradient exists over the area, with the southeast being more moist and the northwest drier. However, the gradient may be related to available moisture, because it is more evident from plant communities than from the recorded precipitation; moisture is more evenly distributed throughout the year in the southeast, and soils are probably more fully developed.

The study area is a relatively level plateau, divided by steep-walled canyons and dotted by volcanic hills, of which the San Francisco Peaks in the northwest and Green's Peak and Mount Baldy in the southeast are the largest and extend above timberline. Wet areas surround these mountains and occur along the escarpment of the Mogollon Rim and in the high, southeastern part of the plateau. These areas support mixed conifer and spruce-fir vegetation.

METHODS

Terminology

Terminology is often misunderstood, primarily because different definitions have developed with time and different disciplines; therefore, the terms used in this study are defined.

Climax.—Tansley's (1935) polyclimax concept, with modifications explained below, has been adopted. He recognized the following climax types, without distinction as to their relative importance: climatic, edaphic, physiographic, biotic, and fire. In each case, climaxes are named after the factor causing them to differ from climatic climax. Daubenmire (1952) recognized Tansley's definition of climax, but ignored fire and zootic climaxes. This study followed recent precedent (Daubenmire and Daubenmire 1968, Pfister et al. 1977) in ignoring fire as a cause of "climax."

Effects of livestock were excluded in interpreting climax, but natural grazing by native herbivores was taken into account. Unlike Kuchler (1964), a distinction was made between wild and domestic herbivores because diet preferences of animals, the nature and intensities of grazing, and frequency of overgrazing affect vegetation differently.

Union.—A union is a group of plants which exhibit similar changes in local distribution because they have similar ecological limitations (Daubenmire 1952). Several unions often grow on one site, and together form a plant community.

Association.—An association (Daubenmire 1952) is a conceptual term describing actual stands which are environmentally and vegetationally similar, except for effects of historical or chance events. Daubenmire applies the term association only to climax communities. It is the basic unit of vegetation classification and is composed of all unions that are superimposed on the same area.

Habitat type.—Habitat type (Daubenmire 1952, Daubenmire and Daubenmire 1968, Pfister et al. 1977) is used to describe units of land which are capable of producing similar plant associations if undisturbed. Two land areas with obvious differences in measurable environmental factors may fall within the same habitat type, if they are equivalent with respect to plant requirements. For example, a habitat type can occur on two sites with different soils and climatic regimes when greater moisture holding capacity of soils on one site compensates for a drier climate. As long as compensating factors are considered, all habitat types should be distinct from all others in topographic position, nature of soil, hydrologic cycle, temperature relations, nutritive relations, etc. Plants should express differences in habitat through variation in such things as vegetative growth, resistance to disease, distinctive small animal and insect communities, and rate of recovery after disturbance.

Phase.—Phases are variations in climax habitat types which are less distinct than variations between habitat types. They may also represent areas which lack sufficiently detailed studies to allow quantification into habitat types. Such areas may not be included in the study areas because they are geographically or commercially insignificant; they may be represented in the study area as transitional communities more widely and typically found outside the study area. The term is also used to describe variants of habitat types which may be late, long-persistent seral stages. It was not

possible to differentiate, in these latter situations, between late seral and climax communities. Because of their obvious persistence, however, any such distinction would have little meaning to resource managers.

Community type.—A community type refers to recurring vegetation where internal, ecological distinctiveness has not been demonstrated (Daubenmire 1976) or where climax state is uncertain (Hall 1973).

Temperature-moisture relationships.—The terms temperature-moisture or wet-dry are used for simplicity. Temperature and moisture often are the dominant factors affecting vegetation distribution in the study area, but the droughty characteristics of different soils and seasonal temperature patterns are included as major influences. Nutritive influences of different soils are both separate from, and influenced by moisture characteristics and are also intended to be a part of the temperature-moisture categories.

Elevation, topography and aspect, radiation, potential evapotranspiration, and local precipitation patterns belong with the moisture and temperature considerations. The term temperature-moisture category does not mean a simple radiation-precipitation function, but a complex of localized and sometimes compensatory factors, some of which may have more influence on plant growth through other means (e.g. nutrients) than strictly through moisture or temperature.

Grazing intensity.—The terms used to describe grazing influence should be interpreted in the context of the sampling of relatively undisturbed stands. Therefore, moderate and heavy grazing refer to a scale in which "heavy" indicates a stand where species composition has been obviously altered by grazing but not enough to exclude indicators of the original community. Heavy grazing would also represent a situation in which some invader plants were present and obvious, but in which the life-form of the community had not appreciably changed. Only in the Kaibab National Forest, and a few plots in the Coconino National Forest, where it was impossible to find better locations, were communities sampled in which the life-form (Arnold 1950) had been affected by grazing. Moderate grazing disturbance indicates a condition in which grazing influence is obvious in lower cover values for decreaser plants (Dyksterhuis 1949) and higher cover values for increaser plants, but without important changes in species composition of the community. Therefore, the stands sampled would, with the above-mentioned exceptions, be classed as good or excellent by Arnold's (1950) or most other range condition classifications.

Plant Identification

Nomenclature follows that of McDougall (1973) with two exceptions: (1) *Poa longiligula* was retained for longtongue mutton bluegrass, rather than a variant of *P. fendleriana* (mutton bluegrass), because *P. longiligula* is easily recognized by long ligules and appears to have indicator value in the ponderosa pine types; (2) Forest Service nomenclature has been fol-

lowed (Nickerson et al. 1976) for bottlebrush squirrel-tail, *Sitanion hystrix* even though McDougall (based on Wilson 1963) contended that *S. longifolium* has been misidentified in Arizona as *S. hystrix*.

Voucher specimens were sent to Charles Feddema, USDA Forest Service Herbarium Curator, Fort Collins, Colo., for verification and identification of questionable species. Collections were made of most plant species and are on file in Northern Arizona University's Deaver Herbarium.

Vegetation Indicator Species

No published information was available to identify plant species which might have value as indicators of habitat types. A chart, which was based on altitudinal ranges of some common species (Kearney et al. 1960) and modified by the authors' personal knowledge and experience, was developed to reflect moisture requirements. Richard H. Hevly and James M. Rominger of the Department of Biological Sciences, Northern Arizona University, suggested revisions. The revised chart, along with notes taken in the field, helped determine indicator species, plots that represented wet or dry extremes, and helped to check computer groupings for logical consistency.

Plant species were initially and subjectively identified as indicators of habitat types after a number of plots had been measured over a range of physical environments. It was then possible to recognize geographic limits of plant unions and relate these limits to environmental influences such as precipitation patterns, soil development, rockiness, and temperature gradients. In addition, the plant unions themselves were assumed to indicate the existence of environmental factors too complex for ready measurement. Thus, the plant unions were used as an indicator of habitat supported by records of physical factors. Individual plants in those unions were chosen as indicator plants for the unions. As unions were combined into habitat types, plant species were retained as diagnostic indicators of habitat type if they showed a high degree of ubiquity (constance) in one type and were not dominant, frequent, and constant in other types. Ubiquity was measured by the percentage of plots in a type which contained the species. In some cases, it was necessary to add an abundance factor (coverage) below which the plant was not considered to be an indicator of habitat type. The need for an abundance factor resulted from the tendency for dry habitat plants to invade moist sites after disturbance (Daubenmire 1976).

Identification of Potential Vegetation

Stands representing potential vegetation were identified by selection of undisturbed sites, as evidenced by lack of logging activity, distance from livestock water, and administrative or geographical isolation from livestock use. Undisturbed stands served as benchmarks

for recognizing other minimally disturbed sites. However, while such stands were considered ideal, they were not always available. Unless stands met the criteria for minimally disturbed conditions, they were not sampled. Instead of random choice of disturbed sites, sampling was limited to stands where the degree of disturbance could be detected by indicator plants. Recognition of disturbance by plant indicators is a well-established method in the area studied (Arnold 1950, 1955; Bostick;³ Clary and Pearson 1969; Hanson 1924; Talbot 1957), and is based on knowledge of retrogression caused by grazing, fire, or other disturbances.

After partial analysis of data, some communities with unclear ecological status were identified. Investigation of relict areas, range exclosures, and inquiries into past history of the sites were made to clarify ecological status. These investigations became more difficult with progression into drier, more fragile and/or more heavily used areas in the northwest. Further, because of disturbance, it was not possible to relate some communities in the Kaibab National Forest to potential vegetation. Consequently, such unknown entities have been termed community types rather than habitat types.

Sample Plots

A circular, 0.1-acre (375 m²) reconnaissance plot was used for visual estimates of plant cover values. A 49.2-foot (15 m) by 82-foot (25 m), rectangular, analytical plot (Daubenmire and Daubenmire 1968), subsampled with square foot (1 dm) rectangular quadrats, was used to reduce bias in visual estimates of cover.

Analytical plots were used in areas which appeared to be highly representative of a plant association. An effort was also made to intersperse analytical plots with reconnaissance plots in order to provide a check and to continually improve the ability to make accurate visual estimates of cover values.

Species presence was recorded outside plots, as long as the plant community and ecological influences where plants were found were homogeneous with the plot. Therefore, plant frequency data reflect a far larger plot size, approaching a sampling of about 1 acre (0.4 ha) unless lack of homogeneity restricted the available area.

Sampling Procedure

Because 331 plots were sampled throughout northern Arizona, small sample size, coupled with the need to obtain plots representative of potential vegetation, required a subjective sampling method. While the USDA Forest Service and the National Park Service helped to identify areas inaccessible to livestock, allotments in good range condition, and near-virgin timber

³"Principles for judging condition and trend of southwestern woodland ranges," an unpublished report prepared by Vernon B. Bostick for the Southwestern Region of the Forest Service, 1947.

stands, most areas were found by personal inspection of stands. Areas were inspected where topography, proximity to water, and presence of fences indicated low cattle density and disturbance. If suitable, these areas were used in sampling.

Specific plot locations were chosen subjectively to eliminate heterogeneity caused by disturbance or ecological changes and to more effectively sample a full range of environmental factors.

The extremely clumped nature of mature pine forests was sampled in one of two ways: by placing two paired plots adjacent to each other, one in the open and one under the trees; or by placing one plot partly in each area.

Deliberate attempts were made to obtain plots that represented the extreme limits of each community studied. An effort also was made to obtain uniform coverage of the study area by reviewing plot locations after most of the data were collected, then locating plots in areas formerly unsampled. Intentional clustering of plots occurred when areas (1) contained several different communities within a short distance, (2) represented ideally undisturbed conditions, or (3) exhibited extremes of slope and topography within a short distance.

Types of Data Recorded

Parent material, landform, position in the landscape, elevation, slope, aspect, surface stoniness and rockiness, percent of exposed mineral soil, and vascular plant basal area were recorded for each plot. Soil series and types were obtained from soil maps when they were available.

Within the plots, tree species and diameters at breast height (d.b.h.)—4.5 feet (1.36 m)—were recorded. Tree reproduction (trees shorter than 4.5 feet) was counted. In most northern Arizona plant communities, Gambel oak (*Quercus gambelii*) grows to tree form. In the present study, clusters of oak reproduction or sprouts were classed as shrub cover. Tree form Gambel oak was identified whenever a measurable stem existed at breast height. Shrub cover excludes coverage of tree form oaks. Understory canopy cover in plots was recorded by species, using the following cover classes in analytical plots:

- 0.02 = plant present outside the plot.
- 0.1 = plant present inside boundaries of a plot, but not abundant enough to be sampled in the quadrats of an analytical plot.
- 0.9 = plant present in the plot with less than 1% coverage. It would normally be sampled in the quadrats of an analytical plot.
- 1.0 = 1% canopy cover. Plants would be sampled in an analytical plot.
- 2.0 = 1 to 5% canopy cover.
- 3.0 = 5 to 25% canopy cover.
- 4.0 = 25 to 50% canopy cover.
- 5.0 = 50 to 75% canopy cover.
- 6.0 = 75 to 95% canopy cover.
- 7.0 = 95 to 100% canopy cover.

For simplicity, actual percentages instead of class codes were recorded for coverages of 1% or more in reconnaissance plots. The same class codes were used for coverages of less than 1%.

Comments were recorded regarding fire history, logging, grazing, mistletoe, canopy cover, extent of stand, and adjacent communities. Two color photographs were taken of each plot.

Analysis of Data

Data were analyzed in four broad steps: (1) initial subjective analysis, (2) computer-assisted analysis used together with subjective evaluation, (3) review by others familiar with the area and with habitat type classification, (4) modification with further analysis where indicated. The analytical method used here is more completely described below and by Franklin et al. (1970) and Pfister and Arno (1980). Mueller-Dombois and Ellenberg (1974) describe and evaluate the methods used.

Initial analysis.—After the first summer of field work, 29 species or pair of species believed to be indicators of the different ecological conditions were chosen. Parent material was added to the list, and an association table was made, by plot, for the 196 plots completed that summer. Plots were arranged to place them in discrete groups based on different moisture-temperature regimes sampled. Subjective impressions of moisture-temperature regimes were based on precipitation patterns known (Jameson 1969) or surmised from local topography and climatic patterns. Soils, aspect, slope, and plant indicators also helped to determine moisture-temperature categories for plots. The classification thus formed was used in the initial stages of computerized ordinations (Mueller-Dombois and Ellenberg 1974) to test the logic of groupings.

Computer analysis.—Ordination analysis is a technique that is useful to assess similarities and differences among sets of vegetation data. Whittaker (1973) has provided an in-depth analysis of the application of ordination analysis in classification of plant communities. Procedures and strategies for using ordinations and computer programs to implement them, produced by Gauch (1973), were used in this study. Polar (Bray Curtis) ordination (Gauch 1973) was used in an iterative process, refining and changing initial groupings on the basis of all data available.

Field work during the second summer provided an opportunity to fill in gaps in the data, increase sample size, and obtain samples in new areas. The entire data base was then reanalyzed, using the same methods, to give a habitat type classification.

RESULTS

The habitat types identified appear in table A1. Association tables for selected species occurring in the habitat and community types appear in table A2.

The following field key may be used to identify sites which represent the habitat types, community types, and phases in the ponderosa pine forests of northern Arizona.

To use this key effectively, these guidelines must be followed:

1. Ponderosa pine should be the actual or potential dominant canopy tree. Stands containing more than minor amounts (5-10 stems per acre more than 4 inches d.b.h.) of white fir (*Abies concolor*) or southwestern white pine (*Pinus strobiformis*), or more than 15 stems per acre of Douglas-fir (*Pseudotsuga menzeisii*) should be classified using Moir and Ludwig's (1979) key.
2. A stand should be selected that has the least amount of disturbance. If it is severely disturbed, the habitat type, phase, or community type can best be determined by extrapolating from adjacent stands occupying similar sites.
3. The stand should be examined carefully to determine species composition by canopy cover, because diagnostic species can have low densities or cover in some circumstances.
4. After the stand has been keyed, it should be carefully compared with the group description and association table (table A2) to determine if it fits the description.

Field Key

- 1a. *Arctostaphylos pungens*, *Quercus turbinella*, or *Quercus arizonica* present ————— *Pinus ponderosa*/
Arctostaphylos pungens CT
- 1b. All of the above plants absent ————— 2
- 2a. *Muhlenbergia virescens* present (*M. montana* is similar in appearance; check identification carefully) ————— 3
- 2b. *Muhlenbergia virescens* absent ————— 7
- 3a. *Festuca arizonica* present ————— 4
- 3b. *Festuca arizonica* absent ————— 6
- 4a. *Bouteloua gracilis* present ————— *Pinus ponderosa*/
Muhlenbergia virescens-
Festuca arizonica-
Bouteloua gracilis CT
- 4b. *Bouteloua gracilis* absent ————— 5
- 5a. *Quercus gambelii* common (**) ————— *Pinus ponderosa*/
Muhlenbergia virescens-
Festuca arizonica HT, *Quercus gambelii* P
- 5b. *Q. gambelii* minimal/absent (**) ————— *Pinus ponderosa*/
Muhlenbergia virescens-
Festuca arizonica HT,
Muhlenbergia virescens-
Festuca arizonica P
- 6a. *Quercus gambelii* common (**) ————— *Pinus ponderosa*/
Muhlenbergia virescens HT,
Quercus gambelii P

- 6b. *Quercus gambelii* minimal/absent (**) — *Pinus ponderosa*/
Muhlenbergia virescens HT,
Muhlenbergia virescens P
- 7a. *Festuca arizonica* present ————— 8
- 7b. *F. arizonica* absent ————— 10
- 8a. *Bouteloua gracilis* present with more than 1% coverage ————— *Pinus ponderosa*/*Festuca arizonica* HT, *Bouteloua gracilis* P
- 8b. *B. gracilis* absent or present with less than 1% coverage ————— 9
- 9a. *Quercus gambelii* common (**) ————— *Pinus ponderosa*/*Festuca arizonica* HT, *Quercus gambelii* P
- 9b. *Q. gambelii* minimal/absent (**) — *Pinus ponderosa*/*Festuca arizonica* HT, *Festuca arizonica* P
- 10a. *Bouteloua gracilis* present ————— 12
- 10b. *B. gracilis* absent ————— 11
- 11a. Stand located on the north rim of the Grand Canyon ————— *Pinus ponderosa*/*Poa longiligula* CT
- 11b. Stand located elsewhere in northern Arizona ————— *Pinus ponderosa*/*Poa fendleriana* CT
- 12a. *Artemisia tridentata* present ————— *Pinus ponderosa*/*Bouteloua gracilis* HT, *Artemisia tridentata* P
- 12b. *A. tridentata* absent ————— 13
- 13a. Parent material composed of fine cinders; stand occurring in cinder hills area northeast of Flagstaff, Arizona — *Pinus ponderosa*/*Bouteloua gracilis* HT, *Andropogon hallii* P
- 13b. Parent material and location otherwise ————— 14
- 14a. *Cowania mexicana* present with more than 2% coverage ————— *Pinus ponderosa*/*Cowania mexicana* CT
- 14b. *C. mexicana* absent or with less than 2% coverage ————— 15
- 15a. *Pinus edulis* present — *Pinus ponderosa*/*Bouteloua gracilis* HT, *Pinus edulis* P
- 15b. *P. edulis* absent ————— 16
- 16a. *Quercus gambelii* common (**) ————— *Pinus ponderosa*/*Bouteloua gracilis* HT, *Quercus gambelii* P
- 16b. *Q. gambelii* minimal/absent (**) — *Pinus ponderosa*/*Bouteloua gracilis* HT, *Bouteloua gracilis* P

(**) Gambel oak is considered common if there are more than 5 trees per acre or if its shrub cover is more than 1%. It is considered minimal if there are fewer than 5 tree stems per acre and its coverage as a shrub is less than 1%.

General Characteristics of the Types

The key identifies 4 ponderosa pine habitat types, 12 phases, and 5 community types. Relative amplitudes of major diagnostic species, and distribution of the habitat types, phases, and community types on a mesic to xeric environmental gradient, are presented in figure 2.

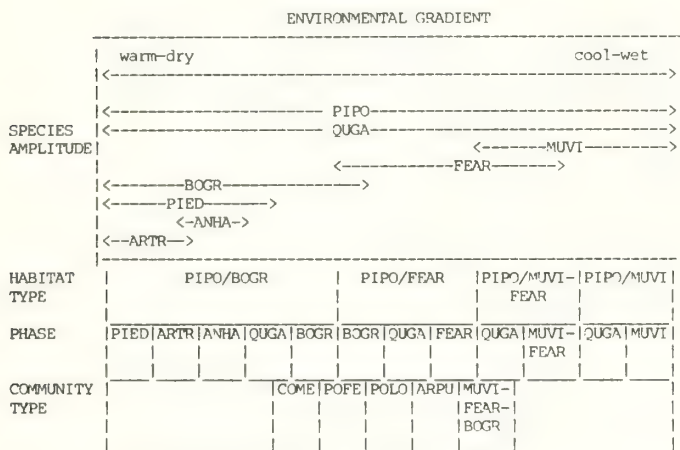


Figure 2.—Schematic distribution of trees and diagnostic understory species on a warm-dry to cool-wet environmental gradient. The distribution of the habitat types, phases, and community types is also shown on the same environmental gradient. The abbreviations used for the species are as follows: ANHA—*Andropogon hallii*, ARPU—*Arctostaphylos pungens*, ARTR—*Artemisia tridentata*, BOGR—*Bouteloua gracilis*, COME—*Cowania mexicana*, FEAR—*Festuca arizonica*, MUVI—*Muhlenbergia virescens*, PIED—*Pinus edulis*, PIPO—*Pinus ponderosa*, POFE—*Poa fendleriana*, POLO—*Poa longiligula*, QUGA—*Quercus gambelii*. QUGA, BOGR, PIED, and ARTR may have broader limits given significant disturbance conditions.

Mesic types are typically in areas of higher annual and summer precipitation, orographic uplift, higher elevations, northeasterly aspects, gentle slopes, cooler summer temperatures, shorter summer droughts, and deeper loamy soils. Xeric types have opposite characteristics, with soils tending to be very fine or very coarse.

Phases within each habitat type are based on significant variations in shrub and/or herb layers. Each habitat type has a Gambel oak (*Quercus gambelii*) phase which represents persistent late seral (climax on some sites) stands with significantly different vegetation, resource potential, and management implications.

Such stands are classed as phases rather than community types, because Gambel oak forms a persistent stage near equilibrium with other plants. In many areas of the Southwest, Gambel oak is clearly a successional species, although it may persist for more than 150 years after a disturbance such as fire. On some sites, such as ridge and mountain summits, it can be a component of a climax community (Hanks and Dick-Peddie 1974). On the Colorado Plateau, Gambel oak is

sometimes successional, but usually occupies an uncertain niche. For example, Gambel oak phases appear to be self-perpetuating members of the climax community under natural tree spacing, perhaps involving fire ecology. While dense pine spacing often results from fire protection, Gambel oak tends to disappear after the large, old oak trees die. Gambel oak stands are very near climax and persistent in most situations and, consequently, have been classed as phases of habitat types.

It appears that continuing work in New Mexico may result in a ponderosa pine/Gambel oak habitat type.⁴ If so, that type is ecologically distinct from the Gambel oak phases of these habitat types and should not be confused with them.

HABITAT TYPE DESCRIPTIONS

1. *Pinus ponderosa*/Muhlenbergia virescens (ponderosa pine/screwleaf muhly) habitat type

This type is the wettest ponderosa pine habitat type found in the study and is transitional to mixed conifer forests in many areas. The habitat type occurs in two phases, *Muhlenbergia virescens* and *Quercus gambelii*.

a. *Muhlenbergia virescens* phase (ponderosa pine/screwleaf muhly HT, screwleaf muhly P)

Distribution

The screwleaf muhly phase (fig. 3) occurs in the Apache-Sitgreaves National Forest and the south half



Figure 3.—Ponderosa pine/screwleaf muhly HT, screwleaf muhly P (plot 80), Wildcat Point, Apache National Forest, 7,640 feet (2,330 m) elevation. Dense, old growth stands support a variety of forbs and less screwleaf muhly.

⁴Personal communication with John A. Ludwig, New Mexico State University, Las Cruces; and William Moir, now with the USDA Forest Service, Southwestern Region, Albuquerque, N. Mex., 1980.

of the Coconino National Forest. It is found near the Mogollon Rim, at elevations ranging from 6,700 to 8,100 feet (2,040 to 2,470 m), on basalt, sandstone, limestone, and alluvial parent materials. More than 65% of the sites sampled were on rolling plateaus and gentle canyon sides with south and west exposures.

Soils have a loamy texture, and plots were in the Sponseller, McVickers, Soldier, and Wildcat soil series. Relatively deep litter and humus layers are typical.

Vegetation

Ponderosa pine is well represented in all size classes. The mean basal area for ponderosa pine is 87 square feet per acre (19.5 m² per ha), which is relatively high for habitat types reported in this study and for Arizona pine forests in general (Clary 1975, Ffolliott and Solomon 1976). Ponderosa pine reproduction (trees shorter than 4.5 feet, or 1.37 m, tall) averaged 220 stems per acre (544 per ha). Small trees of white fir, southwestern white pine, and Douglas-fir are occasionally found in this phase, but are never a component of the climax canopy and are always "accidental" (fewer than 5-10 stems per acre, or 12-25 per ha). When these trees are present in greater numbers, stands should be classified as mixed conifer habitat types (Moir and Ludwig 1979). Shrubs are a minor component in the screwleaf muhly phase of the ponderosa pine/screwleaf muhly HT. Screwleaf muhly is the dominant climax herbaceous species, with a mean cover of 16% (maximum 80%). Other common herbaceous species include groundsel (*Senecio wootonii*), pine dropseed (*Blepharoneuron tricholepis*), pseudocymopterus (*Pseudocymopterus montanus*), and sedge (*Carex* spp.).

Discussion

Fires occur with moderate frequency in this phase; most stands showed some evidence of past fires, but few showed signs of extensive crown fires. Most stands showed evidence of past logging, but it was mostly old activity and relatively light compared to other habitat types. Grazing was light to moderate in 80% of the stands. Mistletoe damage was light to moderate in 77%.

If the stand density of ponderosa pine is allowed to increase in this phase, shrub and herbaceous vegetation will probably decrease. In contrast, reducing stand density could not only increase herbaceous vegetation, but might also increase Gambel oak in the shrub layer.

b. *Quercus gambelii* phase (ponderosa pine/screwleaf muhly HT, Gambel oak P)

Distribution

The Gambel oak phase (fig. 4) is more common than the screwleaf muhly phase of this habitat type. It oc-



Figure 4.—Ponderosa pine/screwleaf muhly HT, Gambel oak P (plot 122), Barney Pasture, Coconino National Forest, 6,820 feet (2,079 m) elevation. White fir and Douglas-fir occur in small drainages and on gentle north slopes, showing the mesic nature of this type.

curs in the north half of the Coconino National Forest between Oak Creek Canyon and Sycamore Canyon, in the south half of the Coconino National Forest, and in the Apache-Sitgreaves National Forest. In these areas, it is near the Mogollon Rim and occurs at elevations between 6,700 to 8,500 feet (2,040 to 2,590 m). At lower elevations, this phase occurs on sandstone, limestone, and alluvial parent materials. On higher locations it is found on basalt, cinder, and conglomerate parent materials. More than 65% of sites sampled were on gentle canyon slopes and rolling plateaus with south and east exposures.

Soils in the ponderosa pine/screwleaf muhly HT, Gambel oak phase, are usually fine sandy loams, with finer textured soils occurring occasionally. More than 65% of the soils occurred in the Overgaard, Sponseller, Broliar, and McVickers soil series, but more than 15 soil types are associated with this phase. Humus and litter layers are developed to a lesser extent than under the screwleaf muhly phase, but still more than most habitat types.

This phase contacts the same communities as the screwleaf muhly phase of the ponderosa pine/screwleaf muhly HT. Northerly exposures support mixed conifer stands, while southwest exposures support

phases of the ponderosa pine/screwleaf muhly-Arizona fescue HT, ponderosa pine/Arizona fescue HT, or ponderosa pine/mutton bluegrass CT. On one site, a distinct change in parent material occurred, with limestone supporting a ponderosa pine/screwleaf muhly HT, Gambel oak phase and basalt soil supporting a ponderosa pine/mutton bluegrass CT.

Vegetation

The mean basal area of ponderosa pine was 91.1 square feet per acre (20.9 m² per ha), the third highest recorded for phases in this study. Ponderosa pine reproduction averaged 126 stems per acre (311 per ha). Gambel oak is present as a tree (1 inch d.b.h. or greater) in more than 80% of these stands. In stands lacking oaks of tree size, shrub cover of oak averages 5% and is always more than 1%. Mixed conifer tree species are occasionally present in very limited amounts in this phase. Screwleaf muhly averages 4% cover, with maximum coverage values of 25%. Increased competition for light and moisture with Gambel oak in this phase reduces herbaceous coverage.

Discussion

Fires have occurred with moderate frequency in the Gambel oak phase, and most fire damage was more than 20 years old. A few stands showed signs of serious crown fires, but plots were excluded from these areas. Succession after an early spring wildfire of varying intensity was reported for this phase by Fitzhugh and Beaulieu.⁵

Logging occurred in most areas, with subsequent varying degrees of thinning. Grazing and mistletoe infection were light to moderate in 70% of the stands. Grazing capacity has been reduced during the past 50 years in this phase because of fire protection and the encroachment of dense pine sapling thickets. The presence of dense oak thickets reduces the potential for livestock carrying capacity, although it is still high compared to most ponderosa pine habitat types.

Gambel oak should be considered a persistent species in late successional stages. It may increase if pine competition is removed. The importance of this type in providing browse, dens, and mast may be considerable, and can be enhanced by practices that induce oak sprouting and retain older trees which serve as dens for small mammals and birds. This phase could develop very slowly into the screwleaf muhly phase, but over such a long time span to be impractical for management to enhance such development.

Any disturbance to the site in this phase may result in increased densities of Gambel oak and New Mexican

locust (*Robinia neomexicana*). Species easily established by seeding after site disturbance include intermediate wheatgrass (*Agropyron intermedium*), orchardgrass (*Dactylis glomerata*), bromes (*Bromus* spp.), and sweetclover (*Melilotus* spp.).

2. *Pinus ponderosa*/Muhlenbergia virescens-Festuca arizonica (ponderosa pine/screwleaf muhly-Arizona fescue) habitat type

This is a moderately mesic ponderosa pine habitat type in which screwleaf muhly and Arizona fescue are codominants in the herb layer. Pseudocymopterus and sedge are common. The habitat type occurs in two phases. Additionally, the ponderosa pine/screwleaf muhly-Arizona fescue-blue grama community type, described later, is a secondary successional stage in this habitat type.

a. *Muhlenbergia virescens-Festuca arizonica* phase (ponderosa pine/screwleaf muhly-Arizona fescue HT, screwleaf muhly-Arizona fescue P)

Distribution

This phase (fig. 5) is common in the Apache-Sitgreaves National Forest and adjacent areas in the southern Coconino National Forest and is found occasionally in the San Francisco Peaks area near Flagstaff, Ariz. It is usually further north of the Mogollon Rim on drier sites than either phase of the ponderosa pine/screwleaf muhly habitat type and occurs at elevations ranging from 6,900 to 9,200 feet (2,100 to 2,804 m). At higher elevations, the phase is usually found on exposed ridges and escarpment edges with basalt parent materials, while lower elevation sites occupy sandstone and limestone parent materials.



Figure 5.—Ponderosa pine/screwleaf muhly-Arizona fescue HT, screwleaf muhly-Arizona fescue P (plot 85), Middle Mountain, Apache National Forest, 8,480 feet (2,585 m) elevation. This type is highly productive of both timber and forage, but regression is easily induced in the plant community.

⁵Final report "Wildlife effects on plant and animal communities in Arizona ponderosa pine forests," by E. Lee Fitzhugh and Jean T. Beaulieu, 1975, for cooperative agreement 16-454-CA, Rocky Mountain Forest and Range Experiment Station. The Station's headquarters is in Fort Collins, in cooperation with Colorado State University.

More than 80% of the soils were sandy or silty loams and occurred in the McVickers, Sponseller, Soldier, and Hogg soil series.

The phase is found on moist sites in climax ponderosa pine types. In wetter areas, it is adjacent to the ponderosa pine/screwleaf muhly HT or to mixed conifer stands dominated by white fir and Douglas-fir, with Arizona fescue, screwleaf muhly, and mountain muhly (*Muhlenbergia montana*) as herbaceous dominants. The screwleaf muhly-Arizona fescue phase occurs in contact with the ponderosa pine/Arizona fescue HT on drier sites.

Vegetation

Ponderosa pine is the dominant canopy tree and reaches its highest basal area (94.4 square feet per acre; 21.7 m² per ha) in this phase. Ponderosa pine reproduction averaged 240 stems per acre (593 per ha). Screwleaf muhly averaged 8% cover, with maximum values of 40%; Arizona fescue averaged 11% cover, with maximum cover values of 55%.

Discussion

Logging has been generally light, but some stands have been heavily cut in recent years. Grazing has been light to moderate in this phase. Mistletoe occurs at light, moderate, and heavy levels with nearly equal frequencies. This phase produces some of the best timber and forage among the ponderosa pine habitat types.

b. *Quercus gambelii* phase (ponderosa pine/screwleaf muhly-Arizona fescue HT, Gambel oak P)

Distribution

The Gambel oak phase of the ponderosa pine/screwleaf muhly-Arizona fescue HT (fig. 6) occurs in the same geographic areas and elevational ranges as the screwleaf muhly-Arizona fescue phase. It is found on limestone, sandstone, and basalt parent materials with equal frequency. The phase occurs more frequently on steep canyon slopes which vary more in exposure than sites supporting the screwleaf muhly-Arizona fescue phase. The Gambel oak phase occurs on more than nine soil series and is characterized by rockier soils than the screwleaf muhly-Arizona fescue phase.

Vegetation

Ponderosa pine basal area was 85 square feet per acre (19.7 m² per ha), and ponderosa pine reproduction averaged 240 stems per acre (593 per ha). Gambel oak is common as a tree and a shrub. Both screwleaf muhly and Arizona fescue have substantially lower average cover values (4% and 2%, respectively) than in the



Figure 6.—Ponderosa pine/screwleaf muhly-Arizona fescue HT, Gambel oak P (plot 96), Stone Creek near Thomas Creek, Apache National Forest, 8,000 feet (2,438 m) elevation. This phase of the HT is less productive, occurs on steeper, rockier areas, and has greater wildlife value than the screwleaf muhly-Arizona fescue phase.

screwleaf muhly-Arizona fescue phase. Arizona fescue, because of its lower shade tolerance, shows a much larger cover reduction than screwleaf muhly.

Discussion

The Gambel oak phase of the ponderosa pine/screwleaf muhly-Arizona fescue HT represents a very persistent late seral stage which would return slowly, if at all, to the screwleaf muhly-Arizona fescue phase. The Gambel oak phase contacts the same communities as the screwleaf muhly-Arizona fescue phase.

Fires were more common and destructive in this phase of the habitat type than in the associated phase. Light to moderate amounts of mistletoe were found. This phase is probably less suitable for livestock use than the screwleaf muhly-Arizona fescue phase, because of reduced forage, steeper terrain, and erosion susceptibility. The Gambel oak phase is more diverse and, therefore, more valuable to wildlife than the screwleaf muhly-Arizona fescue phase.

3. *Pinus ponderosa*/*Festuca arizonica* (ponderosa pine/Arizona fescue) habitat type

The ponderosa pine/Arizona fescue HT is an intermediate (relative to xeric or mesic) climax ponderosa pine forest type. It occurs in three phases: *Festuca arizonica*, *Quercus gambelii*, and *Bouteloua gracilis*.

a. *Festuca arizonica* phase (ponderosa pine/Arizona fescue HT, Arizona fescue P)

Distribution

The Arizona fescue phase (fig. 7) is centered in the Coconino National Forest in the vicinity of Flagstaff,



Figure 7.—Ponderosa pine/Arizona fescue HT, Arizona fescue P (plot 152), south of Kendrick Park, Coconino National Forest, 8,010 feet (2,441 m) elevation. This habitat type and phase is common near Flagstaff, Ariz., and is subject to rare episodic regeneration under natural conditions.

Ariz. It occurs occasionally in the Apache-Sitgreaves and in the southern part of the Kaibab National Forests. It ranges in elevation from 6,800 to 9,200 feet (2,070 to 2,800 m), and is most common on basalt parent material, although it occurs on sandstone and limestone. The phase is found on essentially flat areas of less than 10% slope in the majority of situations, although stands can occur on slopes greater than 40%. The phase occurs on more than 10 soil series, of which Brolliar soils are the most common.

The Arizona fescue phase is a climax type, and occurs in contact with mixed conifer stands dominated by white fir, Douglas-fir, and Arizona fescue (Moir and Ludwig 1979). Among ponderosa pine forests on wetter sites, it is adjacent to the ponderosa pine/screwleaf muhly-Arizona fescue habitat type, and on drier sites, the ponderosa pine/blue grama HT. Where vertisol soils occur adjacent to the Arizona fescue phase, they may support a ponderosa pine/blue grama type. The Arizona fescue phase on vertisol soils may be converted easily to a ponderosa pine/blue grama plant community by factors that reduce ground cover.

The Fort Valley, Wing Mountain, and Taylor Woods plots of the Fort Valley Experimental Forest are near the mesic limit of this phase on soils of igneous origin. Much of the Beaver Creek area is near the xeric limit of the phase. The Long Valley Experimental Forest is also located in this phase at its mesic border with the ponderosa pine/screwleaf muhly-Arizona fescue HT but, in contrast, is on limestone-derived soils. Timber volumes of ponderosa pine at Long Valley are some of the highest in the Southwest—35,000 board feet per acre (Schubert 1974).

Vegetation

Ponderosa pine has a mean basal area of 91.3 square feet per acre (20.9 m² per ha), and stand

reproduction averaged 118 stems per acre (292 per ha). Arizona fescue is the dominant herbaceous species on the basis of foliar cover, averaging 13% cover, with maximum values of 65%. Both buckbrush (*Ceanothus fendleri*) and mountain muhly are very common. Mountain muhly has broader limits of environmental tolerance than Arizona fescue and is less predictable in its occurrence, thus limiting its utility as an indicator species.

Discussion

Mistletoe was present in moderate to heavy amounts. The Arizona fescue phase is relatively well suited to both logging and grazing. It occurs on some of the most accessible terrain and, as a result, has been overexploited.

Areas which are heavily grazed in spring show increased levels of mountain muhly, reduced levels of Arizona fescue, and invasion by blue grama, broom snakeweed (*Gutierrezia sarothrae*), pingue (*Hymenoxys richardsonii*), and a wide variety of forbs (Arnold 1950). Areas grazed by sheep, particularly in summer and autumn, have dense Arizona fescue stands and an absence of mountain muhly and forbs, although pingue is more abundant. Heavy soils on moist sites that are heavily disturbed tend to revert to minute muhly (*Muhlenbergia minutissima*). In contrast, lighter soils on drier sites tend to revert to cheatgrass (*Bromus tectorum*). Arizona fescue has nearly been eliminated in places by extreme and persistent misuse (Leiberg et al. 1904), followed by subsequent encroachment of dense ponderosa pine stands. Many low-lying meadows which tend to hold water in early spring still have not regenerated to pine, even though they were logged about 100 years ago. These microsites often contain abundant spike muhly (*Muhlenbergia wrightii*). Whether spike muhly was abundant before the logging is unknown. Incomplete site preparation may reduce natural regeneration of pine, because chemical exudates from fescue inhibit germination and early growth of seedlings (Rietveld 1975). Other sites, such as Garland Prairie, developed dense fescue stands and resisted pine reestablishment for as long as 100 years. Buckbrush tends to increase in this and other moderately wet habitat types after fire. Intensive grazing by livestock or wildlife soon after germination will greatly reduce the number of buckbrush seedlings. Deliberate management, both for trees and for livestock, is required to maintain this phase in a productive state.

b. *Quercus gambelii* phase (ponderosa pine/Arizona fescue HT, Gambel oak P)

Distribution

The Gambel oak phase (fig. 8) is found in the same physical situations as the Arizona fescue phase of the habitat type, except Gambel oak tends to occur more on rock outcrops and slopes. The phase is sometimes



Figure 8.—Ponderosa pine/Arizona fescue HT, Gambel oak P (plot 288), Janice Tank north of Blue Ridge, Coconino National Forest, 6,860 feet (2,091 m) elevation. This phase occurs on rockier sites and usually has lower productivity than the Arizona fescue phase.

found on small (0.25 to 1 acre; 0.10 to 0.41 ha) inclusions of rocky areas within a general area supporting the Arizona fescue phase.

Vegetation

Vegetation of the Gambel oak phase is dominated by ponderosa pine, which averages 79 square feet of basal area per acre (18.1 m² per ha). Ponderosa pine reproduction averaged 56 stems per acre (138 per ha). Gambel oak is common as a tree and averages 5% cover as a shrub. Arizona fescue averages 5% cover with maximum values of 40%. Mountain muhly is common.

Discussion

The Gambel oak phase is a persistent, late successional community which is similar in origin and interpretation to the Gambel oak phases of the ponderosa pine/screwleaf muhly and ponderosa pine/screwleaf

muhly-Arizona fescue habitat types. It is in contact with the same habitat types as the Arizona fescue phase.

Mistletoe conditions in the Gambel oak phase are similar to those in the Arizona fescue phase of this habitat type. It is not as well suited for grazing as the Arizona fescue phase because of reduced forage production and the presence of oak thickets. Timber production and potential is also less in this phase. The Gambel oak phase is probably very important to wildlife, particularly when it occurs as islands surrounded by the Arizona fescue phase.

c. *Bouteloua gracilis* phase (ponderosa pine/Arizona fescue HT, blue grama P)

Distribution

This phase (fig. 9) occurs in the Coconino and south Kaibab National Forests, with scattered stands on the western side of the Apache-Sitgreaves. Stands range in elevation from 5,400 feet (1,650 m) on plateau areas removed from the Mogollon Rim to 8,700 feet (2,560 m) on the southeastern flanks of the mountainous areas



Figure 9.—Ponderosa pine/Arizona fescue HT, blue grama P (plot 275), Government Prairie, Kaibab National Forest, 7,300 feet (2,225 m) elevation. This area typifies ponderosa pine regeneration problems.

near Flagstaff and Williams, Ariz. More than 80% of the sites occurred on gentle slopes or flat areas. This phase is found on drier sites than the other two phases of the habitat type.

The blue grama phase contacts the ponderosa pine/screwleaf muhly-Arizona fescue habitat type in very moist situations and the other two phases of the ponderosa pine/Arizona fescue HT in intermediate situations. It also adjoins the ponderosa pine/blue grama HT—primarily the Gambel oak and pinyon (*Pinus edulis*) phases—in drier areas, such as southwestern exposures. Basalt and cinder parent materials and thin soils, primarily the Broliar and Sponseller series, are typical of the blue grama phase.

Vegetation

Arizona fescue and blue grama are the dominant herbaceous species, averaging 9% and 3% coverage, respectively. Gambel oak occurs sporadically, but is rarely important in these stands. Ponderosa pine has a mean basal area of 50 square feet per acre (11.5 m² per ha) and only 31 stems per acre (77 per ha) of regeneration.

Discussion

In the absence of disturbance, Arizona fescue is the dominant grass species. However, these sites are dry enough that blue grama would be expected in a mature community. Given any significant disturbance, Arizona fescue will decrease and blue grama will increase. Therefore, this represents a climax phase which is relatively fragile and likely to undergo regression into drier types under conditions of overuse.

Mistletoe occurred in moderate to heavy amounts in this phase. Ponderosa pine reproduction is similar to that in the Arizona fescue phase, but the blue grama phase may be subjected to severe spring drought. Low and wet areas, which tend to form frost pockets and exhibit poor soil aeration, and areas with high densities of Arizona fescue are extremely difficult to regenerate naturally with ponderosa pine.

Much of the area southeast of Williams, Ariz., characterized by ragweed (*Ambrosia psilostachya*) and other forbs, belongs to this phase. Soil damage may have occurred on those sites in the past, and recovery may require cultural treatments or management practices that increase desirable ground-cover densities.

4. *Pinus ponderosa*/*Bouteloua gracilis* (ponderosa pine/blue grama) habitat type

This is the driest ponderosa pine habitat type in northern Arizona. Variation within the habitat type can be partitioned into five phases: *Bouteloua gracilis*, *Pinus edulis*, *Quercus gambelii*, *Andropogon hallii*, and *Artemesia tridentata*. The habitat type is characterized by open, low density stands with lower plant basal area and coverage and more exposed soil surfaces than other habitat types.

a. *Bouteloua gracilis* phase (ponderosa pine/blue grama HT, blue grama P)

Distribution

This phase (fig. 10) occurs most commonly in the southern portions of the Kaibab and northern areas of the Coconino National Forests and is absent in the northern part of the Kaibab National Forest and the New Mexico portion of the Apache-Sitgreaves National Forest. It ranges in elevation from 6,600 to 7,200 feet (2,010 to 2,190 m) on plateaus and mesas. Basalt is the typical parent material supporting Broliar and Sponseller soils.

The blue grama phase is a climax ponderosa pine association which occurs adjacent to pinyon-juniper forests in drier areas and the ponderosa pine/Arizona fescue habitat type in wetter stands.

Vegetation

Mean basal area of ponderosa pine was 35 square feet per acre (8.0 m² per ha), and stocking averaged 43 stems per acre (106 per ha). Blue grama is the diagnostic herbaceous species (mean cover 3%); screwleaf muhly and Arizona fescue are absent. Redroot eriogonum (*Eriogonum racemosum*) is common.

Discussion

Fire is not a major factor in this phase, except that ground fires may eliminate or reduce pinyon and juniper invasion in some areas. Mistletoe is light to moderate in this phase.

This is a dry phase, with the lowest potential timber production of any phase in ponderosa pine forests. Grazing potential is also low, because most range grasses are difficult to establish. Western wheatgrass (*Agropyron smithii*) and bottlebrush squirreltail are among the better adapted species. Some stands south of Williams, Ariz., have been devastated, with the her-



Figure 10.—Ponderosa pine/blue grama HT, blue grama P (plot 177), Kaibab Lake, Kaibab National Forest, 6,820 feet (2,079 m) elevation. This is a dry habitat type with low productivity.

baceous layer now dominated by ragweed. Where this is the situation, soil damage may have occurred, and recovery may be long and difficult in the absence of costly cultural treatment.

b. *Pinus edulis* phase (ponderosa pine/blue grama HT, pinyon P)

Distribution

This is one of the driest ponderosa pine types (fig. 11). It is found on basalt and limestone soils in the Coconino and southern portion of the Kaibab National Forests at elevations ranging from 6,300 to 7,100 feet (1,920 to 2,160 m). The phase occurs on at least four different soil series.

Transition areas between climax ponderosa pine and pinyon-juniper forests support this phase. It is climax, occurring at the lower limits of the ponderosa pine type.

Vegetation

Ponderosa pine has a basal area of 63 square feet per acre (14.5 m² per ha), and small size class pinyon is common. Ponderosa pine reproduction averaged 12 stems per acre (30 per ha). Blue grama averaged 7% cover and redroot eriogonum was common.

Discussion

Timber and forage productivity appear to be greater than in the blue grama and sand bluestem phases of this habitat type. Fires probably reduce the amount of pinyon and juniper, while logging may encourage the establishment or importance of these two species.

c. *Quercus gambelii* phase (ponderosa pine/blue grama HT, Gambel oak P)

Distribution

The Gambel oak phase of the ponderosa pine/blue grama HT (fig. 12) occurs in the southern part of the Kaibab, Coconino, and Apache-Sitgreaves National Forests at elevations ranging from 6,700 to 7,500 feet (2,040 to 2,290 m). It is found on rolling plateaus and gentle canyon side slopes underlain with limestone, sandstone, basalt, or cinder parent materials.

On drier sites, it abuts pinyon-juniper forest types, and on wetter areas, the ponderosa pine/Arizona fescue HT.

Vegetation

Ponderosa pine has a mean basal area of 57 square feet per acre (13.0 m² per ha). Ponderosa pine reproduction averaged 47 stems per acre (116 per ha). Gambel oak is a common tree and/or shrub. Blue grama averaged 2% cover.



Figure 11.—Ponderosa pine/blue grama HT, pinyon P (plot 130), Tufa Mountain, Coconino National Forest, 6,300 feet (1,920 m) elevation. This is one of the driest phases of the driest ponderosa pine type, forming a broad ecotone to the pinyon-juniper woodland.



Figure 12.—Ponderosa pine/blue grama HT, Gambel oak P (plot 297), Scott Tank, Kaibab National Forest, 7,280 feet (2,834 m) elevation. This phase is wetter than the pinyon and big sagebrush phases of the same habitat type.

Discussion

This phase is at or near climax. Gambel oak would diminish slowly over time in most stands, resulting in increasing herbaceous coverage. Fires occur more frequently in this phase than in other phases of the habitat type. Recovery from old logging and grazing disturbance has been slow in these stands. It may be enhanced, however, by minimizing surface disturbances and utilizing range management practices that maintain ground cover adequate for soil protection. Mistletoe is light to moderate in this phase.

d. *Andropogon hallii* phase (ponderosa pine/blue grama HT, sand bluestem P)

Distribution

This is one of the most distinctive phases of any habitat type studied (fig. 13). It occurs only in the cinder cone area in the vicinity of Sunset Crater, near Flagstaff, Ariz. These stands are found on cinder ash parent material at elevations from 6,600 to 7,000 feet (2,010 to 2,130 m). The data indicate that more detailed study in this area may result in further subdivision of this phase and possible elevation of the phase to habitat type status.

The sand bluestem phase of the ponderosa pine/blue grama HT is a climax association that occurs adjacent to pinyon-juniper forests in drier areas. In wetter sites, it abuts the blue grama, pinyon, and Gambel oak phases of the habitat type.

Vegetation

Ponderosa pine has an average basal area of 38 square feet per acre (8.61 m² per ha). It has relatively normal diameter growth in these areas, but poor height growth. Ponderosa pine regeneration averaged 22



Figure 13.—Ponderosa pine/blue grama HT, sand bluestem P (plot 131), Tufa Mountain, Coconino National Forest, 6,820 feet (2,079 m) elevation. This is a very scenic type with high wildlife value, low timber productivity, and fragile cinder soils.

stems per acre (54 per ha). Sand bluestem occurs in 50% of the stands. It is absent in all other phases and habitat types except in the blue grama phase adjacent to the sand bluestem phase. Blue grama occurs in all stands, but is often present in small amounts (average cover 1%). Many areas have extremely low species diversity. Most of the ground surface in these stands is covered by pine litter and exposed cinders. Apache plume (*Fallugia paradoxa*) is common in the shrub layer in some stands which typically have higher species diversity.

Discussion

Fires tend to be unimportant because of sparse vegetation, and grazing is generally light because of lack of available water. Mistletoe incidence is also light. The soil surface is known to reach temperatures lethal to protein. Ponderosa pine reproduction usually occurs in the shade of a shrub, log, or other forms of cover offering protection from the direct rays of the sun, indicating a possible planting technique. Observations indicate that depressions in the soil may place plant seeds in closer proximity to moist soil layers and thus enhance germination and survival.

This phase appears to have limited value for timber or forage production. It is, however, strikingly scenic, with considerable recreational potential, as evidenced by the existence of Sunset Crater National Monument and the amount of off-road vehicle use. Also, shrubby hillsides receive heavy deer use in winter. Regardless of the kind of use made of the phase, the fragile and easily mixed soils may require greater than normal protection, because they are likely to be damaged by disturbance, especially by recreational vehicles or heavy equipment. If the less permeable layers are destroyed, water will quickly percolate below the root zone and trees and vegetative cover may be eliminated (Pearson 1950). Furthermore, plants are easily uprooted by trampling or vehicles and may require a long time for replacement.

e. *Artemisia tridentata* phase (ponderosa pine/blue grama HT, big sagebrush P)

Distribution

The big sagebrush (*Artemisia tridentata*) phase (fig. 14) occurs primarily on the south rim of the Grand Canyon and occasionally on the north rim at edges of ponderosa pine forests. The phase ranges in elevation from 6,300 to 7,400 feet (1,930 to 2,260 m) on limestone parent material. Areas for which soils had been mapped were in the Soldier-Hogg association.

Vegetation

Ponderosa pine has an average basal area of 52 square feet per acre (12.0 m² per ha). Ponderosa pine reproduction averaged 117 stems per acre (289 per ha). Big sagebrush is the dominant species in the shrub



Figure 14.—Ponderosa pine/blue grama HT, big sagebrush P (plot 159), Rowe Well, Kaibab National Forest, near South Rim, Grand Canyon, 6,640 feet (2,024 m) elevation. Influenced by Great Basin climate, this phase is probably better expressed in Utah.

layer, averaging 4% cover. Blue grama cover averaged 7%. Small pinyon trees are common, and redroot eriogonum is an important forb.

Discussion

Stands in Grand Canyon National Park that have not been grazed by livestock for more than 40 years still show the influence of heavy grazing. Mistletoe ranges from light to heavy. Evidence indicates that there is competition for forage between livestock and deer in this phase, partly because of depleted range conditions resulting from historical overuse from both classes of animals. Invasion by less valuable annual plants tends to occur in such areas where the soil surface has been disturbed and is especially prevalent after mechanical disturbance by equipment during timber harvesting operations. Western wheatgrass is adapted to these sites, however, and can be sown on disturbed areas. Seed must be sown on the loosened soil before rainfall, otherwise crust formation will prevent seed burial and subsequent establishment of grass.

This phase is probably common in Utah and could prove to be extensive. If so, it should be elevated to habitat type status.

COMMUNITY TYPE DESCRIPTIONS

1. *Pinus ponderosa*/*Poa longiligula* community type (ponderosa pine/longtongue mutton bluegrass CT)

This community is restricted to the north rim of the Grand Canyon, in the north Kaibab National Forest (fig. 15). It ranges in elevation from 6,800 to 8,400 feet (2,070 to 2,560 m) on gentle canyon slopes of limestone parent material. Several steep, rocky sites supporting this community had high levels of Gambel oak as both a tree and a shrub.

The community is in contact with mixed conifer forests described by Moir and Ludwig (1979), which are dominated by white fir, Douglas-fir, quaking aspen (*Populus tremuloides*), and oregon grape (*Berberis repens*). On drier sites, the community is adjacent to the ponderosa pine/blue grama HT, big sagebrush phase, and to pinyon-juniper forests.

Ponderosa pine has a mean basal area of 80 square feet per acre (18.4 m² per ha), with 64 stems per acre (158 per ha) of reproduction. Longtongue mutton bluegrass averaged 4% cover. Oregon grape and groundsel (*Senecio multilobatus*) are very common in this community.

This community type is successional and has experienced exceptionally heavy grazing in the past (Rasmussen 1941). Herbaceous disturbance has been so great and so widespread that it is impossible to define the original climax community or the end point of the present succession. It is possible that Arizona fescue was once an element in the herbaceous layer of this community, because it occurs in some mixed conifer stands in the area (Merkle 1962, Rasmussen 1941,



Figure 15.—Ponderosa pine/longtongue mutton bluegrass CT (plot 258), Orderville Canyon, Kaibab National Forest, North Rim, Grand Canyon, 8,520 feet (2,597 m) elevation. Pinyon, blue grama, and big sagebrush may invade drier sites in this type after disturbance.

Moir and Ludwig 1979). Its absence in the ponderosa pine area is probably a result of excessive disturbance.

This community type is suitable for timber production. It is also important for wildlife, especially big game, because it constitutes the summer range for the Kaibab deer herd.

2. *Pinus ponderosa*/*Poa fendleriana* community type (ponderosa pine/mutton bluegrass CT)

This community occurs in the Coconino National Forest south of Flagstaff, Ariz., at elevations from 6,500 to 7,200 feet (1,980 to 2,190 m) (fig. 16). It is found on basalt, sandstone, and limestone parent materials. The soils are usually in the Brolliar or Soldier series.

Blue grama, Arizona fescue, and screwleaf muhly are absent in these stands. Mutton bluegrass is the dominant, averaging 2% cover. Ponderosa pine has an average basal area of 72 square feet per acre (16.5 m² per ha). Ponderosa pine reproduction averaged 177 stems per acre (289 per ha). Gambel oak is common as a tree and shrub. Mountain muhly is also common.

Some plots in this type were undisturbed relict areas and occurred on sites wetter than the ponderosa pine/Arizona fescue HT. Other plots were moderately to heavily disturbed, often on sites drier than the normal ponderosa pine/Arizona fescue HT. Because two different communities may exist, further study is needed. One is a moderately disturbed, fragile, transitional community between the ponderosa pine/blue grama HT and the ponderosa pine/Arizona fescue HT. The herbaceous layer is sparse and species diversity is relatively low. The community has been logged, burned, and grazed at moderate to heavy levels in the past. Perhaps Arizona fescue was once a minor component in this community and has disappeared because of disturbance. The community is found adjacent to the



Figure 16.—Ponderosa pine/mutton bluegrass CT (plot 125), Hog Hill, north of Turkey Tank, Coconino National Forest, 7,000 feet (2,134 m) elevation. This type produces little forage in a moderate rainfall zone.

ponderosa pine/Arizona fescue HT, blue grama and Gambel oak phases, and the ponderosa pine/blue grama HT, blue grama, and Gambel oak phases.

The other community is a wetter climax community which occurs between ponderosa pine/Arizona fescue and ponderosa pine/screwleaf muhly, Gambel oak phases in limited areas of the Coconino National Forest.

Observations indicated that this wetter community was characterized by fine-textured soils which often had been damaged by logging and grazing activities during wet periods (Schubert 1974). In general, soils near the Mogollon Rim in the Coconino and Kaibab National Forests showed evidence of damage of this nature. Soil compaction and overgrazing cause dramatic increases in minute muhly and various forbs. Good site preparation is necessary for successful seeding of grasses. Complete recovery under reduced livestock grazing pressure may take more than 100 years (Clary 1975).

3. *Pinus ponderosa*/*Arctostaphylos pungens* community type (ponderosa pine/pointleaf manzanita CT)

This community complex (fig. 17) contains late seral and/or climax stands which are more typical of areas below the Mogollon Rim escarpment. This ponderosa pine type burns frequently because of its chaparral influences, and assessment of its successional status is difficult and arbitrary. More intensive sampling will likely reveal several xeric ponderosa pine types that are transitional to pinyon-juniper and chaparral habitats.

The community occurs sporadically in the Apache-Sitgreaves and Coconino National Forests, near the Mogollon Rim, on basalt, sandstone, and alluvial parent materials. It ranges in elevation from 6,000 to 8,700 feet (1,830 to 2,650 m) on gentle to steep slopes, and occurs on several different soil series.

Soils are often coarse and likely to have poor moisture-holding capacity. This community is probably best viewed as a persistent, late seral community which burns often enough to prevent attainment of a climax state. It is found adjacent to the Gambel oak phases of the ponderosa pine/screwleaf muhly and ponderosa pine/screwleaf muhly-Arizona fescue HT's. Disturbance increases shrub and juniper components of this type.

Ponderosa pine has a mean basal area of 57 square feet per acre (13.1 m² per ha), with reproduction of 52 stems per acre (128 per ha). Gambel oak is common as a tree and a shrub. Pointleaf manzanita (*Arctostaphylos pungens*) is common, as are shrub liveoak (*Quercus turbinella*) and Arizona oak (*Q. arizonica*). In some areas, Pringle manzanita (*Arctostaphylos pringlei*) or greenleaf manzanita (*A. patula*) may also be components of this community. Screwleaf muhly is present in wetter stands, while in drier or disturbed stands, blue grama is common. Occurrence of mistletoe is heavy.



Figure 17.—Ponderosa pine/pointleaf manzanita CT (plot 233), Dagnal Hollow, Sitgreaves National Forest, 6,400 feet (1,951 m) elevation. This type is better expressed below the Mogollon Rim outside the study area.

This type may occur in corridors of animals migrating below the Mogollon Rim in winter. More intensive sampling below the Mogollon Rim is required to fully describe and classify the variability of this community.

4. *Pinus ponderosa*/Cowania mexicana community type (ponderosa pine/cliffrose CT)^a

The ponderosa pine/cliffrose community (fig. 18) was observed in areas west of Pinedale, Ariz. Ponderosa pine is the dominant tree, and cliffrose (*Cowania mexicana*) the dominant shrub, with blue grama and mountain muhly the dominant grasses. Both igneous and sedimentary parent materials support the cliffrose type. Plots containing some cliffrose occurred from 6,700 to 7,450 feet (2,044 to 2,272 m) elevation, but between 6,840 and 7,080 feet (2,086 and 2,159 m) elevation, plots contained at least 2% cliffrose cover. The type is limited to warm sites in ponderosa pine forests. It usually occurs in rough, rocky topography, which may reflect rooting or moisture requirements of cliffrose.

^a*Cowania stansburiana* is a commonly used synonym for *C. mexicana*.



Figure 18.—Ponderosa pine/cliffrose CT (plot 187), near Heber, Ariz., Apache-Sitgreaves National Forest, 6,840 feet (2,085 m) elevation. This type is important for deer because it provides abundant browse on rough, rocky sites, often interspersed within other habitat types that are on gentler topography.

Stands which contained cliffrose varied greatly in associated vegetation and other characteristics. Further investigation of their position in an ecological classification is desirable.

The ponderosa pine/cliffrose type provides an important source of browse for herbivores. Because of the browse and associated rough topography, it is well adapted to support big-game animals. It is frequently interspersed on rocky areas in other habitat types and provides important variety for wildlife in these areas.

5. *Pinus ponderosa*/Muhlenbergia virescens-Festuca arizonica-Bouteloua gracilis community type (ponderosa pine/screwleaf muhly-Arizona fescue-blue grama CT)

The ponderosa pine/screwleaf muhly-Arizona fescue-blue grama CT (fig. 19) is a seral stage of the ponderosa pine/screwleaf muhly-Arizona fescue HT. The seral stage was found in the Apache-Sitgreaves National Forest near Springerville, Ariz., at elevations from 6,800 to 8,800 feet (2,070 to 2,680 m). Sites are



Figure 19.—Ponderosa pine/screwleaf muhly-Arizona fescue-blue grama CT (plot 102), Loco Knoll Tank, Apache National Forest, 8,520 feet (2,597 m) elevation. This is a seral type, with large numbers of forb species reminiscent of grazing disturbance.

relatively dry slopes and rolling plateaus on basalt and sandstone parent materials supporting several soil series.

The community occurs on drier ponderosa pine/screwleaf muhly-Arizona fescue HT's that have been disturbed by grazing and logging. The sites are successional and have more ubiquitous species characteristic of disturbance than the two phases of the habitat type. Stands contact the ponderosa pine/screwleaf muhly and ponderosa pine/screwleaf muhly-Arizona fescue HT's.

Ponderosa pine has a basal area of 65 square feet per acre (15.0 m² per ha). Ponderosa pine reproduction averaged 103 stems per acre (254 per ha) on these plots. Gambel oak occurs sporadically, but is rarely abundant, and alligator juniper (*Juniperus deppeana*) is common in small size classes. Pinyon seedlings occur in several stands. Screwleaf muhly, Arizona fescue, and blue grama are the dominant herbaceous species, averaging 7%, 5%, and 1% cover, respectively.

This community should slowly return to a ponderosa pine/screwleaf muhly-Arizona fescue HT under management practices that lessen disturbance and soil erosion, enabling the understory to recover. There is evidence that continued disturbance can cause invasion by pinyon and blue grama.

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APPENDIX

The data described below have been placed on deposit as supportive documentation which may be of interest to field personnel, managers, or other parties. The information is available from Timber Management Research, Rocky Mountain Forest and Range Experiment Station, Forestry Sciences Laboratory, Northern Arizona University, Flagstaff, AZ 86001.

1. Species encountered in the field sampling.
2. Soils associated with each forest community.
3. Mean percentage of plot surfaces covered by (a) exposed mineral soil, (b) rocks, (c) litter, (d) moss, and (e) vascular plant basal area summarized for each forest community.
4. Field forms containing information on the location, physical site factors, vegetation, and related observations for each of the 331 plots sampled.
5. Forest maps showing the location of each plot.
6. A computerized association table for each forest community. Each community is described on a plot by plot basis and then summarized using data on 10 species of trees, 11 species of shrubs, and 66 herbaceous species.
7. Computerized data base arranged by plot from 1 to 331.
8. Photographs of each plot, usually including closeup and distant scenes.

Table A1.—Ponderosa pine forest habitat types, phases, and community types of northern Arizona

Habitat type and phase	Abbreviation	No. plots
<i>Pinus ponderosa</i> / <i>Muhlenbergia virescens</i> HT	PIPO/MUVI HT	
<i>Muhlenbergia virescens</i> P	MUVI P	15
<i>Quercus gambelii</i> P	QUGA P	30
<i>Pinus ponderosa</i> / <i>Muhlenbergia virescens</i> - <i>Festuca arizonica</i> HT	PIPO/MUVI-FEAR HT	
<i>Muhlenbergia virescens</i> - <i>Festuca arizonica</i> P	MUVI-FEAR P	40
<i>Quercus gambelii</i> P	QUGA P	24
<i>Pinus ponderosa</i> / <i>Festuca arizonica</i> HT	PIPO/FEAR HT	
<i>Festuca arizonica</i> P	FEAR P	39
<i>Quercus gambelii</i> P	QUGA P	21
<i>Bouteloua gracilis</i> P	BOGR P	28
<i>Pinus ponderosa</i> / <i>Bouteloua gracilis</i> HT	PIPO/BOGR HT	
<i>Bouteloua gracilis</i> P	BOGR P	11
<i>Pinus edulis</i> P	PIED P	6
<i>Quercus gambelii</i> P	QUGA P	19
<i>Andropogon hallii</i> P	ANHA P	16
<i>Artemisia tridentata</i> P	ARTR P	13
Community Type		
<i>Pinus ponderosa</i> / <i>Poa longiligula</i> CT	PIPO/POLO CT	15
<i>Pinus ponderosa</i> / <i>Poa fendleriana</i> CT	PIPO/POFE CT	10
<i>Pinus ponderosa</i> / <i>Arctostaphylos pungens</i> CT	PIPO/ARPU CT	12
<i>Pinus ponderosa</i> / <i>Cowania mexicana</i> CT	PIPO/COME CT	4
<i>Pinus ponderosa</i> / <i>Muhlenbergia virescens</i> - <i>Festuca arizonica</i> - <i>Bouteloua gracilis</i> CT	PIPO/MUVI-FEAR- BOGR CT	9
Mixed conifer	—	17
Unclassified	—	2

Table A2.—Summary group association tables for selected species occurring in habitat types and community types^a

	Size class	Habitat types							
		PIPO/MUVI HT, MUVI P	PIPO/MUVI HT, QUGA P	PIPO/MUVI -FEAR HT MUVI-FEAR P	PIPO/MUVI -FEAR HT QUGA P	PIPO/FEAR HT, FEAR P	PIPO/FEAR HT, QUGA P	PIPO/FEAR HT BOGR P	
Trees									
<i>Pinus ponderosa</i>	< 4" dbh	28/100	23/97	25/97	28/92	18/97	15/90	9/89	
<i>Pinus ponderosa</i>	4-12" dbh	6/73	6/83	5/77	9/75	4/74	10/71	6/75	
<i>Pinus ponderosa</i>	> 12" dbh	5/100	6/100	6/100	5/100	5/100	5/100	4/96	
<i>Quercus gambelii</i>	< 4" dbh		15/50	2/3	6/50	4/3	9/62	8/21	
<i>Quercus gambelii</i>	4-12" dbh		4/63	15/3	4/75	2/8	7/67	4/39	
<i>Quercus gambelii</i>	> 12" dbh		3/33		2/46	2/3	1/62	3/36	
Shrubs									
<i>Artemesia tridentata</i>									
<i>Berberis repens</i>			2/7	0/8	0/4	1/10	0/5	0/11	
<i>Ceanothus fendleri</i>		1/47	2/33	1/57	0/63	0/72	1/38	0/18	
<i>Quercus gambelii</i>		0/33	5/90	0/25	1/100	0/28	5/90	3/57	
Grasses									
<i>Andropogon scoparius</i>		0/20	0/13	2/13	0/13	2/23	0/14	2/36	
<i>Aristida arizonica</i>		0/7	0/13	0/8		1/8	1/5	1/43	
<i>Aristida fendleriana</i>				0/3	0/4	0/10		1/14	
<i>Blepharoneuron tricholepis</i>		0/87	0/50	1/62	2/50	1/41	1/38	0/71	
<i>Bouteloua gracilis</i>			0/3					3/100	
<i>Festuca arizonica</i>				11/100	2/100	13/100	5/100	9/100	
<i>Koeleria cristata</i>		2/73	1/70	2/58	2/54	0/38	0/57	4/57	
<i>Muhlenbergia montana</i>		0/13	3/30	1/23	2/33	7/82	4/71	6/75	
<i>Muhlenbergia virescens</i>		16/100	4/100	8/100	4/100				
<i>Poa fendleriana</i>		2/93	3/97	3/70	2/83	3/74	2/95	3/89	
<i>Poa longiligula</i>		1/7	9/10	0/8	1/20	0/3	2/14		
<i>Sitanion hystrix</i>		2/93	2/97	2/87	1/92	2/100	3/100	3/100	
<i>Sporobolus interruptus</i>			1/3		0/4	2/8	2/8	1/25	
Forbs									
<i>Achillea lanulosa</i>		0/53	0/43	0/45	1/42	2/43	0/48	0/29	
<i>Antennaria parvifolia</i>		0/40	0/43	0/40	0/33	0/33	0/43	0/25	
<i>Eriogonum alatum</i>			0/3			0/3	0/5	0/4	
<i>Eriogonum racemosum</i>			0/27	0/8	0/4	0/13	0/57	0/40	
<i>Fragaria ovalis</i>		0/33	0/13	0/20	0/21	0/3	1/5		
<i>Hymenopappus mexicanus</i>		0/33	0/7	0/23	0/12	0/18		0/7	
<i>Lathyrus arizonicus</i>			9/17	0/13	1/17	0/15	0/10		
<i>Lithospermum multiflorum</i>		0/13	0/36	0/27	0/33	0/38	0/19	2/21	
<i>Lotus wrightii</i>		0/73	0/77	0/50	0/92	0/72	0/76	0/57	
<i>Pedicularis centranthera</i>		0/47	0/27	0/15	0/50	0/23	0/23	0/14	
<i>Senecio wootonii</i>		0/60	0/23	0/35	0/42	0/10	0/10		
<i>Solidago sparsiflora</i>		0/27	2/36	0/35	0/42	0/38	0/52	1/18	
<i>Thalictrum fendleri</i>		0/66	0/50	0/48	0/66	0/72	0/23	0/43	
<i>Vicia americana</i>		0/13	0/40	0/38	0/45	0/41	0/62	0/32	

Table A2.—Summary group association tables for selected species occurring in habitat types and community types^a—Continued.

	Size class	Habitat types										Community types									
		PIPO/BOGR		PIPO/BOGR		PIPO/BOGR		PIPO/BOGR		PIPO/BOGR		PIPO/BOGR		PIPO/BOGR		PIPO/BOGR		PIPO/BOGR		PIPO/BOGR	
		P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P
Trees																					
<i>Pinus ponderosa</i>	< 4" dbh	11/100	13/84	7/81	23/77	5/89	22/89	13/92	14/73	33/100	4/75										
<i>Pinus ponderosa</i>	4-12" dbh	4/91	8/63	2/81	4/77	4/67	4/89	4/92	8/93	6/70	4/75										
<i>Pinus ponderosa</i>	> 12" dbh	2/91	4/95	2/100	3/100	5/78	5/100	3/92	7/100	4/90	4/100										
<i>Quercus gambelii</i>	< 4" dbh		6/58		6/15	2/27	7/11	37/67		14/80											
<i>Quercus gambelii</i>	4-12" dbh	1/9	5/79		11/15	4/33	2/33	4/75	13/20	3/90	2/25										
<i>Quercus gambelii</i>	> 12" dbh		3/11				1/44	3/25		1/60	3/25										
Shrubs																					
<i>Artemisia tridentata</i>					4/100				0/20												
<i>Berberis repens</i>		1/9	0/16		1/15	1/11	0/11		1/60	1/30	0/25										
<i>Ceanothus fendleri</i>		0/18	0/16				0/22	0/42	0/47	0/60											
<i>Quercus gambelii</i>		0/45	1/90		3/62	2/67	0/44	8/100	0/27	2/100	0/50										
Grasses																					
<i>Andropogon scoparius</i>		3/18	4/11	0/31	0/8	1/33	2/33	0/17		1/30	0/75										
<i>Aristida arizonica</i>		3/18	0/26	0/31		3/11	0/33	0/25			1/25										
<i>Aristida fendleriana</i>		0/27	0/32	0/13		0/11	0/22	0/58	0/13	2/10											
<i>Blepharoneuron tricholepis</i>		2/45	1/42		1/31	1/56	3/100	1/42	0/13	1/20	2/75										
<i>Bouteloua gracilis</i>		3/100	2/100	1/94	7/100	7/100	1/100	2/75	0/20		4/100										
<i>Festuca arizonica</i>							5/100														
<i>Koeleria cristata</i>		0/73	1/84		2/77	1/67	4/100	1/58	0/40	0/80	0/75										
<i>Muhlenbergia montana</i>		7/64	5/58	9/38	3/23	3/57	5/22	2/33	0/33	5/70	5/100										
<i>Muhlenbergia virescens</i>							7/100	1/75													
<i>Poa fendleriana</i>		5/100	4/100	1/19	4/100	4/78	2/78	2/75	1/93	2/100	3/75										
<i>Poa longiligula</i>		1/9	0/5		0/15				4/100												
<i>Sitanion hystrix</i>		3/100	4/100	1/69	1/92	3/100	3/100	3/92	2/80	1/100	3/100										
<i>Sporobolus interruptus</i>		1/27	1/21			2/22	0/11	2/17		0/10											
Forbs																					
<i>Achillea lanulosa</i>		1/45	0/21			1/11	1/22	1/16	0/20	0/20											
<i>Antennaria parvifolia</i>		0/54	0/31		1/46		0/22	0/16		0/30											
<i>Eriogonum alatum</i>		0/27	0/21	0/6	0/15	0/44	0/44	0/41	0/7		0/50										
<i>Eriogonum racemosum</i>		0/81	0/90	0/6	0/77	0/78	0/44	0/41	0/87	0/50	0/75										
<i>Fragaria ovalis</i>			0/5						0/13	0/10											
<i>Hymenopappus mexicanus</i>							0/22	0/8	0/13												
<i>Lathyrus arizonicus</i>								0/8		27/30											
<i>Lithospermum multiflorum</i>			3/21		0/7	0/11	0/33	0/16	0/27	0/10	0/25										
<i>Lotus wrightii</i>		0/63	0/57		0/46	0/55	0/55	0/66	0/87	0/70	0/50										
<i>Pedicularis centranthera</i>			0/31				0/33	0/25	0/27	0/70											
<i>Senecio wootonii</i>																					
<i>Solidago sparsiflora</i>		2/18	0/52	0/6	0/38	1/33	0/11	0/16	0/73	0/80	0/50										
<i>Thalictrum fendleri</i>		0/36		0/6	0/7	0/22	0/22	0/16	0/20	0/30	0/25										
<i>Vicia americana</i>		1/9	0/15					0/8	1/13	0/70											

^a Occurrence of each species in each habitat type, phase, and community type is indicated by two values separated by a slash. The first indicates the mean density/plot for the two tree species, or the mean coverage/plot for the shrubs, grasses, and forbs. In all cases, however, the first value is the mean for only the plots in which the species was present. The value to the right of the slash is the percent constance for each species in the phase or community type; it is the percentage of the total number of plots in the group in which the species was found. In cases

Hanks, Jess P., E. Lee Fitzhugh, and Sharon R. Hanks. 1983. A habitat type classification system for ponderosa pine forests of northern Arizona. USDA Forest Service General Technical Report RM-97, 22 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Four major habitat types (HT's), divided into 12 phases, are described for the ponderosa pine forests of northern Arizona. In addition, five community types are described for the same area. On a wet to dry gradient, the HT's are (1) *Pinus ponderosa*/ *Muhlenbergia virescens*, (2) *Pinus ponderosa*/ *Muhlenbergia virescens*-*Festuca arizonica*, (3) *Pinus ponderosa*/ *Festuca arizonica*, and (4) *Pinus ponderosa*/ *Bouteloua gracilis*.

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Rocky
Mountains



Southwest



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U.S. Department of Agriculture
Forest Service

Rocky Mountain Forest and Range Experiment Station

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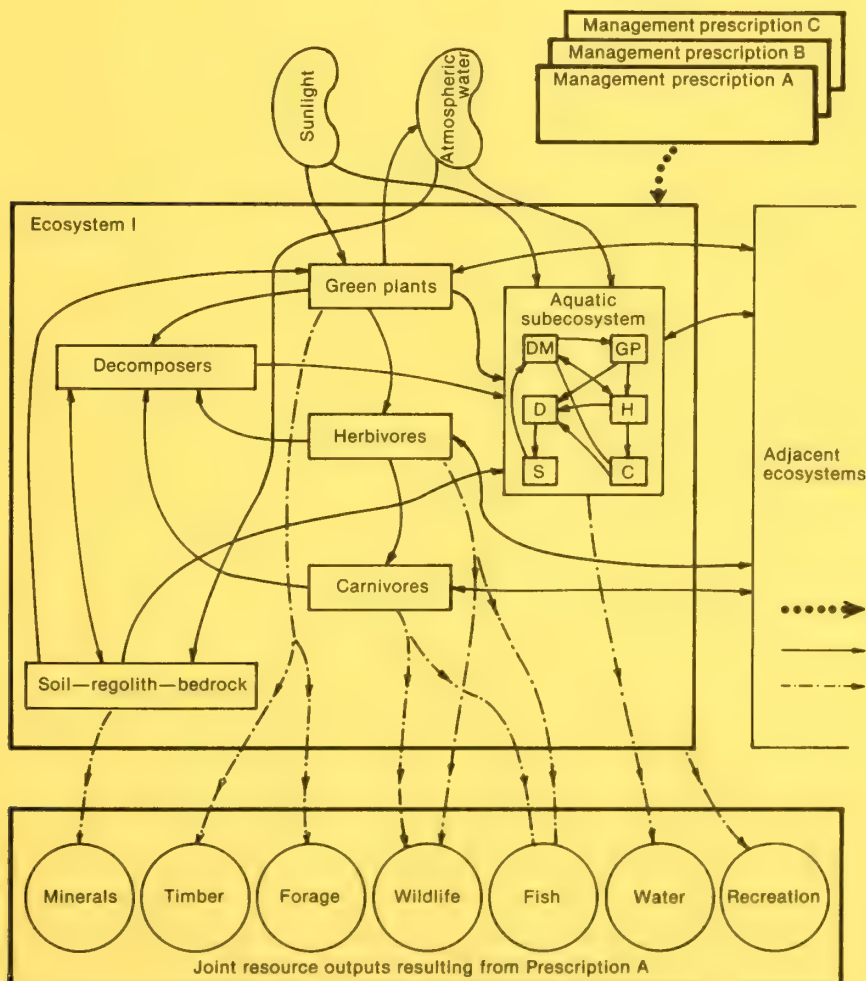
Fort Collins,
Colorado 80526

General Technical
Report RM-98



Analysis of Forage Production for Assessments and Appraisals

John E. Mitchell



Abstract

This report is an overview of the biotic and abiotic ecological factors, including human activities, that affect forage production on forest and rangeland ecosystems. Also discussed are forage production models and how forage quantity and quality can control animal production.

Acknowledgments

The author thanks Drs. James Detling of Colorado State University, Ronald Sauer of Battelle Northwest Laboratories, E. R. Beaty of the University of Georgia, and Harlan DeGarmo of the Soil Conservation Service for their useful ideas and suggestions concerning the contents of this paper.

Analysis of Forage Production for Assessments and Appraisals

**John E. Mitchell, Range Scientist
Rocky Mountain Forest and Range Experiment Station¹**

¹*Headquarters is in Fort Collins, in cooperation with Colorado State University.*

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Analysis of Forage Production for Assessments and Appraisals

John E. Mitchell

Management Implications

An understanding of the ecological factors affecting forage production is necessary if natural resource scientists are to develop models and other analytical tools that will more accurately and precisely estimate the forage response to management practices on specific ecosystems.

Although the present knowledge on this subject is fairly comprehensive in several general areas, it is incomplete in others. Environmental factors related to processes that can be measured aboveground have been described to a much greater degree than those interacting with plants belowground. For example, scientists have described the ecological consequences of light intensity and CO₂ concentration on photosynthesis more exactly than they have described belowground nutrient cycling pathways. Fortunately, increasing research in edaphology, nutrient cycling, and some aspects of ecophysiology is adding to knowledge of belowground ecological processes. Most techniques for estimating forage production on the ground have been known for some time; however, procedures for predicting forage production on the basis of climate, management, and other causal factors are more recently and less finely developed.

Researchers have been able, however, to construct reasonably accurate models of the rate some species and species groups accumulate biomass. To date, such models have tended to be applicable only to specific plant communities, which narrows their usefulness in predicting responses to management at the regional or forest level. Models are being improved so that, within the coming decade, the use of ecological production models is likely to play an important part in resource management procedures. The most apparent obstacle in this modeling is a lack of an accepted general systems theory paradigm applicable to natural ecosystems. A general systems approach is based on the idea that system properties are not a function of characteristics of each ecosystem, but can be applied universally to many ecosystems (Halfon 1979).

This report presents an overview of forage production as an ecological process. It describes production mechanisms for ecological modeling in a way that can be readily synthesized. In addition, it provides the reader who is familiar with basic concepts of ecology with a contemporary picture of what forage production is and, using current analysis tools, how it may be evaluated within the framework of natural resource assessments.

Introduction

Concept of Production

The concept of productivity, developed from the theory of ecosystem trophic structure (Lindeman 1942), is fairly new to ecology. Productivity is closely related to the ecosystem process of energy flow, which begins with short-wave solar energy and ends in the form of organic heat of respiration (Odum 1971). In general, productivity refers to the rate at which energy is bound by organisms in the form of biomass. The units of productivity are most commonly expressed in terms of biomass per unit area per unit time (e.g., g·m⁻²·week⁻¹, kg·ha⁻¹·year⁻¹), although it is sometimes given in terms of energy (e.g., kCal·m⁻²·year⁻¹) (Whittaker 1975). Conversions between energy and biomass have been made (Golley 1961), but the relationships appear to be somewhat dynamic, both among species and temporally within species (Slobodkin 1962, Darling 1976).

Several other terms closely tied to productivity have created confusion in the ecological literature. These terms include words such as production, yield, biomass, phytomass, and standing crop. The relationship between the terms "productivity" and "production" is an excellent example. Although there is little disagreement on

the meaning of productivity as a rate process, the same is not the case for the meaning of production. Texts in pure and applied ecology contain many different definitions, stated or implied, of production. According to the predominant opinion, production is defined as the biomass or energy incorporated into an ecosystem during a specified time period (often a season or a year). As such, both productivity and production are rate processes and may be used interchangeably (Odum 1971). Authors using the term production to describe an amount of accumulated biomass (Smith 1974) have nearly always presumed a time factor as part of their definition. In this report, therefore, the terms productivity and production are used synonymously (Rodin and Bazilevich 1967, ESA-AAAS 1968). Odum (1971) properly suggested that the time interval should always be explicitly stated when the term production is used.

Biomass, unlike production, refers to an amount of live material present at any given time on a per-unit-area basis. It, too, may be expressed in terms of either mass (e.g., g·m⁻², kg·ha⁻¹, lb·acre⁻¹) or energy (e.g., cal·m⁻²). A good illustration of the difference between production and biomass is provided by a bucket with a hole in its bottom, hanging under a running faucet. The rate at which water runs into the bucket would be equivalent to production, and the amount of water in the

bucket at any one time would represent biomass. Mathematically, the relationship between production and biomass is as follows:

If X = biomass

$$\frac{\Delta X}{\Delta t} = \text{change in biomass with respect to time } t$$

$$\frac{\Delta X}{\Delta t} = \text{production} - \text{death}$$

(assuming no emigration or immigration)

To determine biomass from production, one would have to estimate the death function and integrate the equation between times t_1 and t_2 .

Phytomass is a recently coined term referring to plant material only; it is the total mass of plants, including dead attached parts, per unit area at a given time. It differs from biomass because it includes dead attached organic material. Standing crop is generally considered to be synonymous with biomass (Petrusewicz 1967); however, some authors have denoted it as being equivalent to phytomass (Barbour et al. 1980). The meaning of standing crop should be defined when the term is used.

"Yield" has had more of a colloquial use, primarily in applied facets of ecology. According to a preliminary Range Inventory Standardization Committee (RISC) report (Artz et al. 1980), yield is "(1) the quantity of a product in a given space and/or time; (2) the harvested portion of a product." Because of its uncertain and multiple meanings, yield is not commonly used in the ecological literature.

Primary Versus Secondary Production

Primary production refers to the rate of fixation of solar radiation by autotrophic organisms (green plants) through the process of photosynthesis. The total rate at which energy becomes fixed is called gross primary productivity (GPP). Not all of this energy is transformed into biomass, however. In most ecosystems, more than half the energy in GPP is used immediately in respiration to supply the necessary energy for the plant's own metabolism (Woodwell 1970). The remaining fixed energy, stored in plant tissues as biomass, is called net primary productivity (NPP).

Secondary production is the rate at which energy, in the form of organic tissue, is converted into animal biomass by digestion of consumed material. The energetics of secondary production are somewhat more complex than those for primary production. Figure 1 is a schematic representation of the relationship between consumption and secondary production. In brief, secondary production equals assimilation less respiration, while the energy of assimilation equals consumption less food unused (i.e., feces and urine). In addition, not all food removed by the consumer is, in fact, ingested (Mitchell and Pfadt 1974).

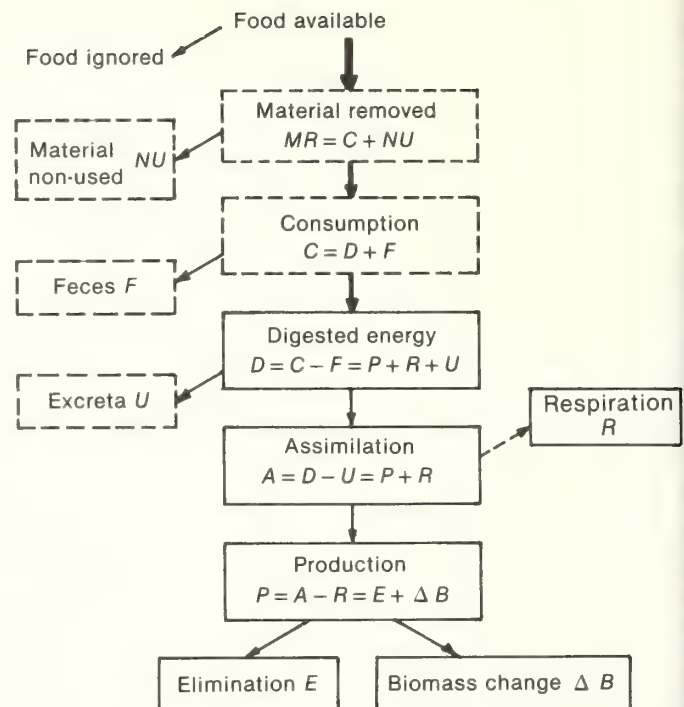


Figure 1.—Schema of energy partitioning between food available and secondary production. Note that biomass dynamics is a function of both production and losses of biomass (E) caused by death and emigration, a relationship that exists at each trophic level. (Adapted from Petrusewicz 1967.)

Secondary production includes the process of animals eating plants (herbivory) and animals eating other animals (carnivory). Herbivores are called either primary consumers or secondary producers in ecosystem-level ecology. Carnivores are also termed secondary consumers.

Actually, from an ecosystem viewpoint, an additional kind of food chain exists besides the herbivore/carnivore chain; it is the detritivore chain or food chain of decay (Odum 1971). This chain cannot be considered in terms of secondary productivity, as such energy is not stored as biomass but, rather, in the form of dead organic matter and decay organism populations. In this review, the detritivore food chain is treated as only a mechanism for converting dead organisms to heat, thereby balancing the ecosystem energetics equation. Phillipson (1966) provides a readable, basic overview of ecological energetics.

In comparison to available energy, neither primary nor secondary production is very efficient thermodynamically. According to Woodwell (1970), considerably less than 1% of the incoming solar energy is used in photosynthesis. This tiny fraction is sufficient, nonetheless, to support the entire biosphere. At the secondary levels of production, the amount of energy transferred varies widely in terrestrial ecosystems. Lindeman's so-called "10 percent law," which states that about 10% to 20% of the energy entering a trophic level can be utilized without perturbing the ecosystem, is probably a reasonable assumption in general terms, at least for natural communities. This ratio of energy

actually fixed through production by a population or trophic level to energy available is called ecological efficiency (E) (Hanson 1962).

The number of trophic levels in an ecosystem is limited by its ecological efficiency. If E is constant, then the energy available at any trophic level would be E^i , where i is the mean number of food-chain links between that trophic level and the autotrophs (Slobodkin 1962). For example, if $E=0.15$ and the system consisted of a grass-mouse-coyote food chain, the coyote would have only about 2% of the energy in the grass incorporated into its production ($0.15^2=0.0225$). This is one reason why terrestrial systems seldom have more than three or four trophic levels.

Comparison of Ecosystem Components and Resource Products

A conceptual difference exists between ecosystem production, and resource products. For example, the process of energy flow addresses the movement of carbon (energy) into, through, and out of an ecosystem. If the carbon entering and leaving primary producer components are integrated over a given time period, the quantity obtained can be converted to biomass outputs which characterize those ecosystem components.

In contrast, resource products refer to specific outputs from ecosystems which provide some use to mankind. Generally, they comprise a subset of outputs from comparable ecosystem components. For example, forage as a resource product only consists of the portion of accumulated plant biomass which is suitable and available for consumption by specific categories of herbivores (Fig. 2). Although relationships exist between primary production and available forage on rangeland ecosystems, objective translation mechanisms generally are not available.

The ecosystem concept began to be used as a basis for natural resource management in the early 1970's. Before then, management connoted manipulation of only the "resource," without regard to the interactions or whole-system responses involved. With the increased sophistication of systems analysis, the enhanced understanding of ecosystem processes and interactions, and recognition of the lack of effective translations between systems ecology and single-resource management concepts, it was clear that an ecosystem-level approach to the subject was necessary. More recently, management has come to denote the simultaneous manipulation of the entire ecosystem, even though some components are obviously affected more than others (fig. 2). For the most part, this paper addresses those ecosystem processes which are related to primary and, to some extent, secondary production.

Techniques for Estimating Production

Direct Estimates

Historically, the concept of primary productivity came before, and served to further, the interest in

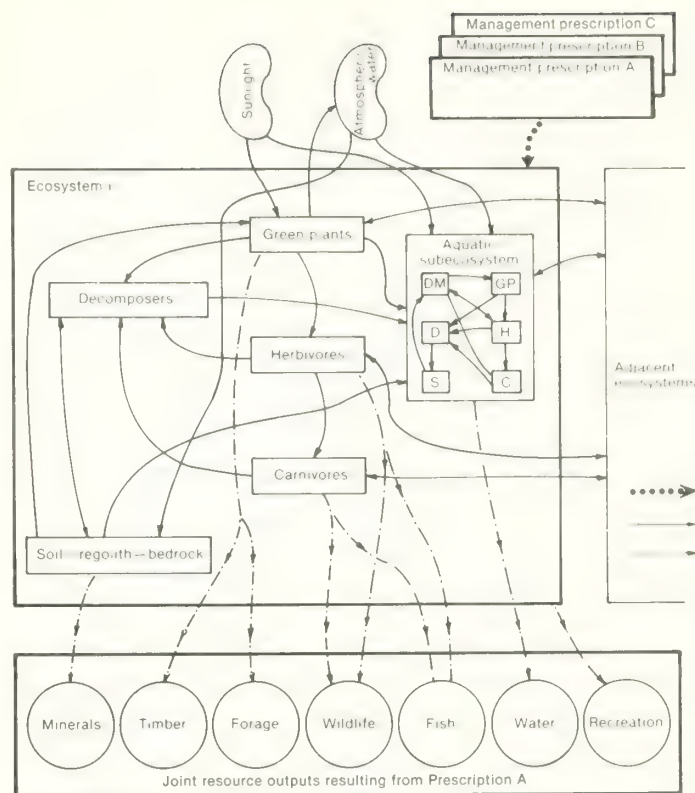


Figure 2.—Ecosystem structure and resource outputs. Management prescriptions are applied to ecosystems, producing an array of resource outputs. Nonresource energy and nutrient losses from ecosystem are implied but not shown.

secondary productivity (Odum 1968). Following this logical flow, primary production and the ways it can be estimated are examined first. Before discussing production, however, it is helpful to outline the difference between direct and indirect production estimators.

Primary productivity is the rate of photosynthesis of all plants in the ecosystem being described, and is expressed in terms of energy transformed. A direct estimate of primary production, then, involves the actual measurement of photosynthesis. Such instantaneous measurements of rate processes $\Delta X/\Delta t$ can be either reported where $\Delta t \rightarrow 0$ or averaged over longer time intervals.

Methods for directly estimating photosynthetic rates are associated with monitoring the change of carbon dioxide or oxygen concentrations during photosynthesis. Carbon dioxide flux is more suited than oxygen flux for estimating photosynthesis, because slight variations in the amount of CO_2 taken up are easier to detect (Sesták et al. 1971). This is because of the small concentration (300 p/m) of CO_2 in the atmosphere in comparison to O_2 .

Woodwell (1970) attempted to estimate GPP of an entire community by monitoring the flux of CO_2 in the canopy, at night, during temperature inversions in order to obtain an estimate of community respiration. His measurements may have been accurate but such estimates can only be considered approximations. Most work on GPP using CO_2 exchange has involved the

monitoring of plants or parts of plants. A comprehensive review of gas exchange, especially as it applies to forage plants, is provided by Moore (1977).

Estimating production indirectly involves relating it, as a dependent variable, to some other measured attribute. For the most part, ecologists have used indirect methods to determine NPP, and their prevalent algorithms have utilized biomass as the directly measured, independent variable.

Biomass as an Estimator of Production

Most forage plants, especially herbaceous species, go through contrasting phenological stages between germination and maturity. Consequently, the respiratory demands of growing or storage tissue and the photosynthetic supply from leaf tissue of varying age and photosynthetic capacity are constantly changing (Moir 1969). This can result in dynamic relationships between NPP and biomass, especially at the community level.

In a monoculture system, a single measure of biomass is adequate to accurately predict production. This is especially true when the species present possesses a C-3, cool-season photosynthetic pathway (C-3 plants, biomass accumulate continuously until soil-water stress or some other factor induces dormancy, with little growth thereafter; in comparison, C-4 plants often have multiple growth periods reflecting precipitation patterns). In such a case, peak standing crop and NPP are nearly equivalent (Wiegert and Evans 1964).

In ecosystems of greater diversity, the standing crop or biomass at any given time is often much less than the NPP (Malone 1968). Each species of such a community may be unique phenologically and, therefore, possess unique rates of development and times of peak standing crop (Singh et al. 1975). Forbs are particularly conducive to shattering after senescence, resulting in their complete absence shortly after maturity. Moreover, according to Moir (1969), species in natural ecosystems, through natural selection, do not generally accumulate the products of NPP in large storage organs or easily harvested parts. This is in contrast to monoculture species, which often have such attributes as a result of selective breeding by man. Therefore, it is likely that community peak standing crop will serve as an adequate indirect estimator of NPP in a simple ecosystem, but not in a diverse ecosystem.

Forested ecosystems do not have NPP levels that approach their standing crop, except during earliest seral stages of succession. Nonetheless, if production and standing crop of only the usable forage in a forest (i.e., herbaceous species and twigs and leaves of browse species) are considered, the concept of community standing crop can serve as a reliable measure of NPP in structurally simple ecosystems. In such cases, the "ecosystem" would be defined only by a forage component.

Odum (1960) discussed the shortcoming of using community peak standing crop to determine NPP and dem-

onstrated that this problem could be minimized by summing the peak standing crop of each species independently. Such a technique, however, may overestimate productivity if a community is dominated by many species with low standing crops (Wiegert and McGinnis 1975). The overestimation results from the inherently high variation in biomass of such species (i.e., because peak standing crop often maintains itself long enough for more than one sample to be taken, use of the highest value obtained overestimates the mean peak standing crop).

The determination of biomass in natural systems is not usually an easy task. If the objective is to estimate NPP on an annual basis, only the current year's growth should be measured, not all living tissue. Graminoids are the easiest group from which to derive biomass data; like all herbaceous species, they die back to the ground each year, and their aboveground parts tend to stay attached to the plant beyond peak standing crop. Forbs, although herbaceous, sometimes have phenological developments in which earlier-developing parts dry and drop from the plant before senescence.

In addition to problems of determining biomass, significant errors in estimating NPP can accrue when vegetation losses are not adequately considered (Wiegert and Evans 1964). Bradbury and Hofstra (1976) found, for example, that including vegetation death in their production estimates in a grassland community increased the estimates by up to 200%.

Woody plants pose a much larger obstacle to estimating biomass than do herbaceous species. To account for biomass accumulated in a given growing season, at least five components must be examined (Whittaker 1962): leaves, twigs, branch growth, stem growth, and root growth. The effort is even more arduous for evergreen species; they require separation of current year's leaves from older leaves and, on some species, the assessment of increase in old-leaf weight (Whittaker 1962). Published work pertaining to woody-plant production is scarce. Most work on trees has, expectedly, focused on the bole, while the preponderance of research dealing with shrubs has dealt with only twigs and leaves or "browse." For examples of total production estimates of trees, see Whittaker et al. (1974) and Grier and Logan (1977). In addition to Whittaker (1962) others who have studied total production of shrubs include Burk and Dick-Peddie (1973) and Caldwell et al. (1977).

Because forage production encompasses only part of woody-plant NPP, this report is limited to assessing twig and leaf production of those species which make up the diet of browsing animals. Even when biomass of browse is limited to twigs and leaves, additional measurement problems exist that are not found with herbaceous species (Pieper 1978). For example, when stimulated by browsing or other factors, shrubs tend to develop twigs emitting from lateral buds, resulting in forage growth scattered throughout the canopy space. Variation in growth flushes in spring and late fall often causes difficulty in distinguishing current year's growth from previous growth. In addition, the nature of evergreen

shrubs sometimes causes a problem in determining new leaf growth. Most researchers have used litter traps to ascertain turnover rates of evergreen leaves as a measure of leaf NPP (Burk and Dick-Peddie 1973).

Given the difficulty of assessing shrub biomass directly by harvest methods, some authors have proposed using various crown measurements to predict biomass nondestructively, a procedure termed "dimension analysis" (Whittaker 1975). Such relationships have been developed for several desert shrub species (Ludwig et al. 1975), chaparral vegetation (Bentley et al. 1970), serviceberry (Lyon 1968), and mountainmahogany (Medin 1960).

In a different approach to predicting shrub production, Irwin and Peek (1979) were able to quantify twig biomass of browse species in the cedar zone of northern Idaho in relation to various silvicultural practices. An objective of their work was to incorporate shrub production into Stage's (1973) Stand Prognosis Model. Their projects were based on regression models, developed from 105 stands, using site factors, habitat type, and time as independent variables.

Nondestructive sampling techniques for estimating biomass of herbaceous species have seen common use, also. Among these methods are ocular estimation (Pechanec and Pickford 1937), the use of capacitance meters (Neal and Neal 1973), beta-particle attenuation techniques (Mitchell 1972), and remote sensing spectral analysis (Pearson and Miller 1973, Tucker 1980). Milner and Hughes (1968) and Mannetje (1978) provide excellent descriptive reviews of both destructive harvesting and nondestructive techniques for sampling herbaceous biomass. Several workers have shown that double sampling provides a more precise estimate of plant biomass than using a harvest method alone (Tadmore et al. 1975); in general, the weight (ocular) estimate technique is used as the fast method and clipping, as the slow method (Francis et al. 1979).

Problem of Fluctuations in Production

Information about NPP during a growing or grazing season is extremely useful to range managers, if long-term records on vegetation response to grazing are lacking (Stoddart et al. 1975). However, there are large variations in the amount of forage produced from year to year. The magnitude of yearly fluctuations appears to be greatest in xeric ecosystems. It was documented four decades ago (Lantow and Flory 1940) and dramatically portrayed more recently by Sharp and Sanders (1978) in a photographic series taken in a long-term study within the salt-desert shrub zone. Stoddart et al. (1975) presented a general discussion of NPP fluctuations.

Fluctuations in production of vegetation are accompanied by shifts in species composition (Miles 1979); however, the extent to which these fluctuations are caused by dynamics in species composition has received little interpretive analysis.

Plant NPP fluctuates both between and within growing seasons (Uresk et al. 1975). The rate of biomass ac-

cumulation by most forage plants is an irregular, interrupted process, reflecting the short-term dynamics of NPP (Sims and Singh 1978). As a consequence, the use of peak standing crop as a measure of NPP for a given species may result in significantly underestimating production, especially in regard to those species with continuous or multiple growing periods interspersed with periods of relative dormancy (Singh et al. 1975). In such cases, a better estimate of NPP would probably be provided by summing positive growth increments during each growing period (Kelly et al. 1974).

Finally, the relationships between fluctuation in NPP and responses in secondary production by herbivores have received little attention. Some work on such ecosystem interactions has been handled through the use of simulation models. Examples of a modeling approach to primary/secondary production interrelationships include grassland and grasshoppers (Rodel 1977), pasture and livestock (Smith et al. 1977), and general consumer/producer relationships in grasslands (French 1979).

Estimating Production of Different Levels of Integration

The concept of levels of integration in ecology is important and broadly accepted (Billings 1978). Essentially, this concept states that, in ecology, the individual organism and its environment, the population and its environment, and the biological community and its environment (ecosystem) form separate, but interacting, hierarchical systems.

The levels-of-integration concept has also been applied, by definition, to various levels of ecosystems (Major 1969). Generally, the definition of ecosystems used by ecologists has reflected the structure and function suited to the topic being addressed. Ecosystems have been defined on the basis of a microcosm encompassing much less than a community (Witcamp and Frank 1970); a single plant community (Golley 1965); a small watershed comprising, perhaps, several plant communities (Mitchell et al. 1975); a group of natural communities dominated by the same species (Grier and Logan 1977); monocultures of human origin superimposed over one to several climax communities (Rauzi 1975); a large region comprising many communities (Sala et al. 1981); and the entire North American grassland (Lauenroth 1979). At the largest scale, some workers have described ecosystems in terms of the entire earth or biosphere (Lieth and Whittaker 1975).

A common thread runs through each of these ecosystems, no matter what its level of integration. That is, each ecosystem must exist in both space and time (Kormondy 1976). The spatial distribution of ecosystems is authentic, according to Kormondy (1976), but their exact outlines are somewhat arbitrary because ecosystems are simultaneously interconnected with other ecosystems, both laterally and vertically, as components of larger systems. In other words, ecosystems are open systems to a greater extent than merely allowing for

solar energy and precipitation inputs and respiratory outputs.

Ecosystems, therefore, can be defined and described from small, localized to large, regional areas. Nonetheless, when addressing primary production (or forage production) as a process, models of such systems have appeared remarkably similar; for example, compare Kelly et al. (1969), Bledsoe (1976a), Sauer (1978), Cale (1979), and Fick (1980). In general, NPP or energy flow rates are controlled mechanistically by abiotic parameters such as heat, water, and soil nutrients, and by biotic factors—primary consumers and decomposers (Innis 1975).

Regardless of its level of integration, ecosystem boundaries have been fixed along natural junctures, based mostly on classifications of vegetation or landform. The incorporation of artificial boundaries based on municipalities or land management agencies poses, to systems ecology, a new problem which has yet to be addressed in the literature. It is apparent, however, that ecological analyses of forage NPP, if handled under existing systems theory, will require ecosystems, as opposed to political and management systems, as a basis for model development.

Some land-management planning models are defined along synthetic boundaries (Ashton et al. 1980). Most of these models utilize mathematical programming algorithms, because optimal solutions are desirable and, hopefully, possible for management systems (Jameson 1970). Forage NPP in these models is generally treated as joint production input functions in terms of animal unit months. Such inputs are not a result of ecological simulation modeling, but, rather, a Delphi process (Linstone and Turoff 1975), involving subjective decisions from groups comprised of scientists, land managers, or both. The justification for a Delphi approach has been based on the premise that providing production outputs from natural systems as a result of management practices does not lend itself to precise analytical techniques but can benefit from subjective judgments on a collective basis. Cooper and Zedler (1980) have proposed using interdisciplinary (ID) teams to describe the responses of ecosystems to developmental or management inputs.

At the National Forest level, land-management planning modeling is based around the linear programming models FORPLAN (Johnson et al. 1980) and (to a much lesser extent on rangelands) Range RAM (Jansen 1976). In both of these cases, however, forage production is not modeled. These are assumed to be known in advance, and are usually obtained through the use of ID teams. With the FORPLAN model, for example, data on forage production as a function of various management prescriptions must be provided, in the form of yield tables, as input into the linear programming matrix.

C. S. Holling and his colleagues (Holling 1978) originated a conceptual framework, "adaptive environmental assessment," as a new process for environmental assessment. Their procedure relies on the formation of a core group comprised of people with analytical skills (e.g., computer programmers and statisticians) and

subject-matter skills (e.g., range scientists, economists). The principal difference between a Delphi procedure and that of Holling is in its method of operation. The adaptive environmental assessment procedure uses an interactive process of core-group meetings to develop models, followed by workshops involving decision-makers and managers who use the models to test and evaluate alternative policies. The core group then meets to evaluate and simplify its models, after which another workshop is scheduled, and so on. A Delphi process is not based on such an interactive technique. Although Holling's method was designed to resolve environmental assessment problems, its concept should be useful in developing techniques for determining joint production inputs of optimization models.

A logical extension of the use of optimization models in natural resource decisionmaking would be to couple production-oriented simulation models of natural systems to the mathematical programming models that allocate land and resources. To date, however, there is little literature on this subject. One simulation model, RANGES, has been written to simulate a grassland ecosystem as a link to range economic models (Gilbert 1975). RANGES is a low resolution model (Van Dyne 1978a), meaning that, in this case, it has few state variables (i.e., component parts defining the ecosystem). (See Patten 1971 for a review of terminology used in systems ecology.) A model with high resolution can be generally categorized as having a relatively large number of state variables, being mechanistic rather than empirical in terms of rate process functions and including many of the real system attributes it is attempting to mimic (Van Dyne and Abramsky 1975). The use of ecosystem NPP models in this manner has been extremely limited; the only example of such work is by Hunter et al. (1976).

Theoretically, it should be feasible to couple ecosystem models with economic or social models. Such mechanistic models would provide a sound conceptual framework on which to base the cause-and-effect relationships found in joint production problems and would allow management impacts to be examined quantitatively (Van Dyne 1978b). No research has yet been published that specifically addresses the problem of merging natural ecosystem boundaries and models with the artificial boundaries of management and economic systems. Present knowledge suggests that the production outputs could be handled within the ecosystem model by treating each natural community as a separate subsystem, provided that the proportion of the natural communities were known for the management system.

Abiotic Factors in Forage Production

As previously mentioned, NPP is the net result of photosynthesis less respiration. Therefore, this discussion addresses abiotic factors as they relate to these two physiological processes. Photosynthesis is primarily dependent upon light, temperature, CO₂ concentration, and water (Daubenmire 1974); however, these factors strongly interact in regulating photosynthesis, requiring

a holistic consideration of their effects (Troughton 1975). The identification, in the past 10 years, of two major photosynthetic pathways (Black 1971) has sharpened our understanding of these interactions. Björkman and Berry (1973) wrote an excellent general review of photosynthesis of C-3 (cool season) and C-4 (warm season) forage plants in relation to light intensity, temperature, CO_2 concentration, and stomatal resistance (a measure of water stress). Figure 3 depicts examples of these generalized relationships: (a) C-4 plants possess a relatively high light saturation point in comparison to C-3 plants; (b) the minimum, optimum, and maximum

cardinal temperatures are significantly higher in C-4 plants; (c) photosynthesis in C-4 plants is greater at leaf CO_2 concentrations below 300 p/m (the minimum CO_2 level where photosynthesis can take place is an order of magnitude lower in C-4 plants—5 versus 50 p/m); finally, (d) because C-4 plants are able to operate more efficiently at low CO_2 concentrations, they can keep their stomata closed to a greater degree (lower stomatal conductance) and, therefore, lose less water through transpiration at a given rate of photosynthesis (i.e., C-4 plants have a much higher photosynthetic water-use efficiency under a water-stressed environment).

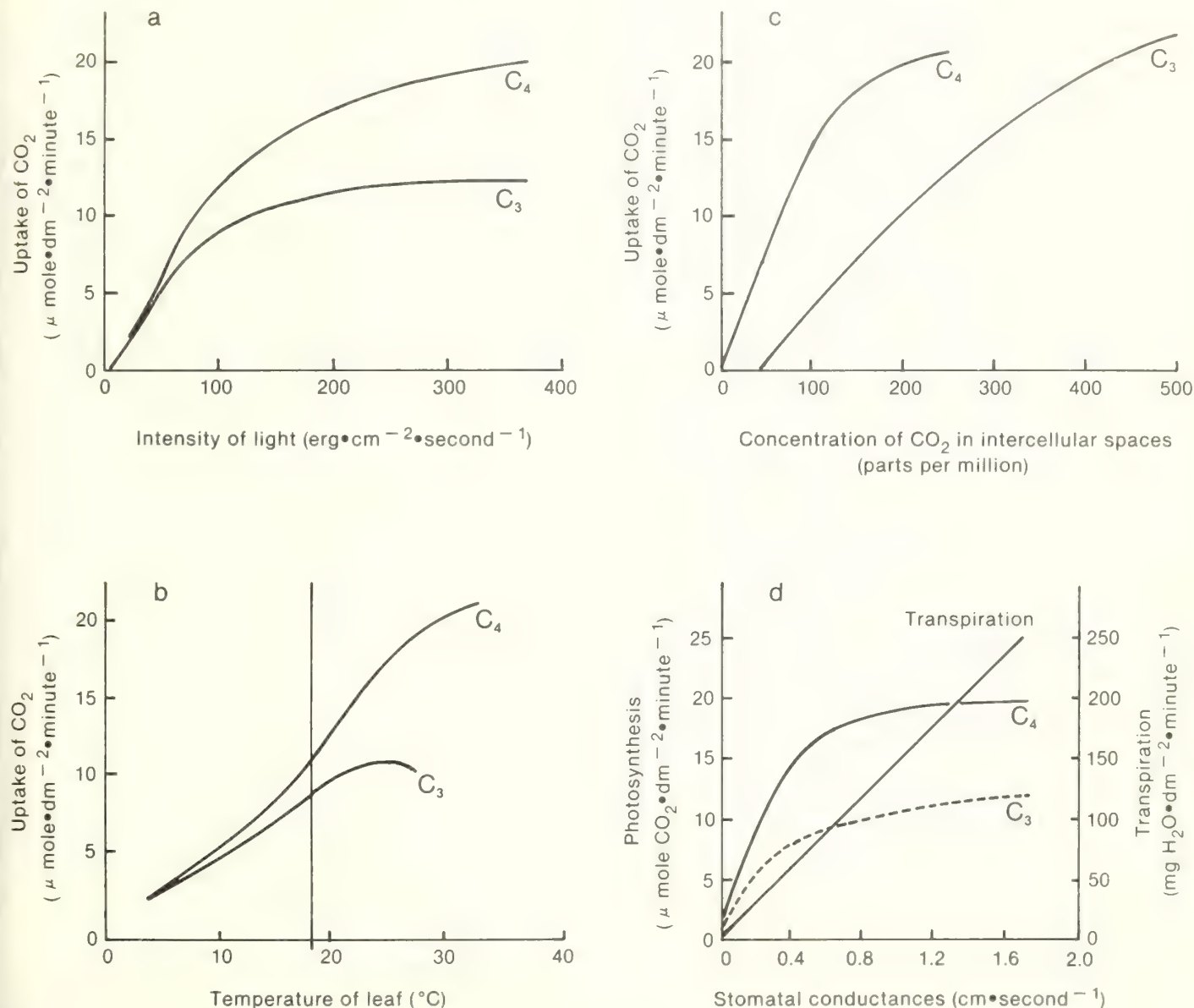


Figure 3.—Photosynthesis of *Atriplex patula* (C-3 plant) and *A. rosea* (C-4 plant) in relation to: (A) light intensity, (B) temperature, (C) CO_2 concentration, and (D) stomatal conductance. (Adapted from Björkman and Berry 1973.)

Climatic Factors

Carbon dioxide concentrations at the leaf surface vary in proportion to wind speed and rate of photosynthesis (Chang 1968); however, the relative importance of CO₂ dynamics in altering NPP for natural forage-producing systems is probably not significant in temperate regions. On grasslands, the canopy is generally insufficient to have a strong attenuating effect on prevailing winds, and in browse-dominated communities, light and temperature are more likely to be limiting factors. As a result, most models simulating NPP primarily utilize light, temperature, and soil water (or precipitation) as exogenous driving variables (Cale 1979; Detling et al. 1979), or just the latter two (Parton 1978), or sometimes only water (Schumacher 1973).

Rice and Parenti (1978) concluded from a field experiment in the tallgrass prairie that higher soil temperature is the main cause of increased NPP after burning or forage removal. They ascribed this relationship to the relatively high optimum temperatures (about 35° C) for growth of the C-4 grasses dominating their study site.

Although primary productivity depends on photosynthesis, NPP is not necessarily closely correlated to the rate of photosynthesis. Respiration, translocation to belowground parts, and other processes constraining a plant's ability to make use of photosynthate, often can have an overriding effect on the accumulation of aboveground biomass (Evans 1975). In fact, the allocation patterns of photosynthate (carbon) by plants into their photosynthetic system (leaves) versus nonphotosynthetic system (support structure, roots) have been postulated to affect NPP as much as or more than carbon gain capacity (Detling et al. 1979). Carbon-gain capacity is defined as the proportion of dry weight of photosynthetic tissue produced in a given time. Mooney (1972) and Thornley (1976) made extensive examinations of carbon allocation in plants and its implications to NPP.

Reductions in NPP caused by increased respiration can be significant, especially in ecosystems characterized by large biomass levels and high temperature (Evans 1975). Early simulation models of community NPP relied upon the assumption that respiration is directly related to leaf area index (LAI) or biomass; however, more recent work has shown that respiration increases geometrically with LAI and is more a function of photosynthesis than of biomass (McCree and Troughton 1966). Further, McCree (1970) proposed, with some basis for acceptance (Penning de Vries 1972), that respiration by plants can be divided into two components: (1) metabolic (maintenance) respiration, related to biomass but temperature-dependent; and (2) synthesis (growth) respiration, related to photosynthetic rate and temperature-independent. These components have not been used extensively in models simulating NPP (Hunt and Loomis 1979 modeled respiration in this way), possibly because the physiological basis for such an approach is relatively new (Thornley 1976). In the Grassland Biome ELM model, for example, aboveground respiration was solely a function of average daytime temperature (Sauer 1978).

The relationship between photosynthesis, respiration, and temperature is more enigmatic when one considers the ability of plants to acclimate photosynthetic and respiration capabilities in response to changing temperature regimes (Barbour et al. 1980). Such an adjustment factor seems much more pronounced in desert plants (Pearcy 1976), which fortunately do not constitute a major source of forage NPP in North America. However, Kemp and Williams (1980) have shown it to occur in both cool- and warm-season grasses on the shortgrass plains; forage production models may eventually consider this acclimation adjustment in simulating mechanistic responses to fluctuating climates.

Nutrients

The role of nutrients as an abiotic factor affecting NPP has received intensive research for many years, focusing first on agricultural ecosystems in terms of fertilizer responses (Black 1968). Work on nutrients and production in natural systems dealt initially with forestland, where mineral cycling can be closely monitored (Tennessee Valley Authority 1968, Likens et al. 1977).

Forage production on pastureland in relation to mineral nutrient supplies received extensive investigation in Great Britain, Australia, and New Zealand before comparable research commenced in the United States (Snaydon 1981, Till 1981). Review papers on the role of nutrients as they affect forage NPP in the United States have been written by Wight (1976) for the northern Great Plains, Jones and Woodmansee (1979) for the California annual grassland, and West and Skujins (1977) for the Great Basin. Adams and Stelly (1962) examined fertility requirements for southeastern species.

These and other papers demonstrate that interactions between mineral nutrients and plant production are complex and difficult to generalize. The synergistic effects between nutrients and other environmental factors often overshadow the direct production response, thereby making mechanistic model building a complicated task. One of the few research efforts involving a holistic approach to describing forage production resulting from variations in nutrient levels and soil water took place on the shortgrass prairie (Dodd and Lauenroth 1979). The authors found increases in aboveground NPP to be by a factor of 2 in response to augmented nitrogen alone, and by an order of magnitude when the fertilizer effect was coupled to additional soil water (fig. 4).

Soil Water

As previously stated, soil water availability can have a substantial influence on variation in forage production, especially where water frequently limits the rate of photosynthesis and leaf growth. Leaf growth has been shown to be one of the processes most sensitive to water stress (Chu and McPherson 1977), and several re-

searchers have pointed out a positive correlation between allocating photosynthate to leaf area development and increased productivity (Christie 1975). There are more implications to the water factor, however, than short-term fluctuations in growth. Protracted effects and interactions are also important.

The long-term consequences of drought on range forage plants can affect NPP under certain conditions for years after precipitation has returned to normal. For example, in a review of drought effects on northwestern ranges, Bedell (1980) showed that recovery of forage NPP is closely tied to past grazing use (i.e., a climate/animal interaction exists). He related lack of restoration of production to decreased carbohydrate reserves and root growth.

The response of vegetation to mechanical land-treatment practices that enhance water availability, such as furrowing, ripping, pitting, and waterspreading, can cause large increases in forage NPP within localized areas, if conditions are suitable (Vallentine 1980).

Other Soil Factors

Each of the factors discussed above (i.e., climatic factors, nutrients, and soil water) are variables known to be significant in predicting NPP dynamics on a given

site. In great part, each affects production by the way it modifies the state of the soil system, both from site to site and for a given site over time. These factors are the principal ones used in predicting forage production.

Plants do not respond solely to climate, nutrients, and water, however. Production is related to the total soil system, including a myriad of physical properties that vary spatially across the landscape. Insights into this complex relationship between forage production and soil properties have developed rapidly during the past 30 years.

Concepts fundamental to understanding the connection between forage production and the soil have been outlined in a notable paper by Shiflet (1973). He defined range site as "a distinctive kind of rangeland which differs from other(s)...in its ability to produce a characteristic natural plant community...based on differences in kinds or proportions of plants making up the climax community or differences in productivity." Shiflet (1973) related the following theory based on the idea of a range site:

- (1) more than one specific soil (defined here as a series or phase of a series—see Soil Survey Staff 1980) may support a single range site; however,
- (2) a single soil should not support more than one range site.

Consequently, from an ecological perspective, any techniques for evaluating ecosystem forage production must consider basic soils information. At the local level, good correlations may be obtained between forage NPP and the soil series category of classification or phase of series (Shiflet 1973).

Regional forage production analysis procedures, in contrast, will not be able to make use of detailed soils properties because of problems associated with keeping track of the tremendous number of soil series in the United States (approximately 12,000 at last count). Although no soil/plant production research comparable to that dealing with range sites has taken place at the regional level, one should expect the same concept to hold, but at a lower resolution associated with higher categories of soil classification (Heerwagen and Aandahl 1961). The soil family, for example, groups soil series having similar chemical and physical properties that affect their response to management (Soil Survey Staff 1975). It may be necessary to use even higher soil classification categories, such as subgroups or great groups, as a classification base for regional forage production models. Nonetheless, the plant-soil relationships still must be considered.

Fire

Fire, as an abiotic factor, influences forage production in several different ways, mostly beneficial. On forestland, fire can remove the overstory canopy, thereby allowing increased light into the understory. On other rangeland ecosystems, fire can be used to control unpalatable shrubs, eliminate thick litter and standing dead layers, provide increased levels of available ash

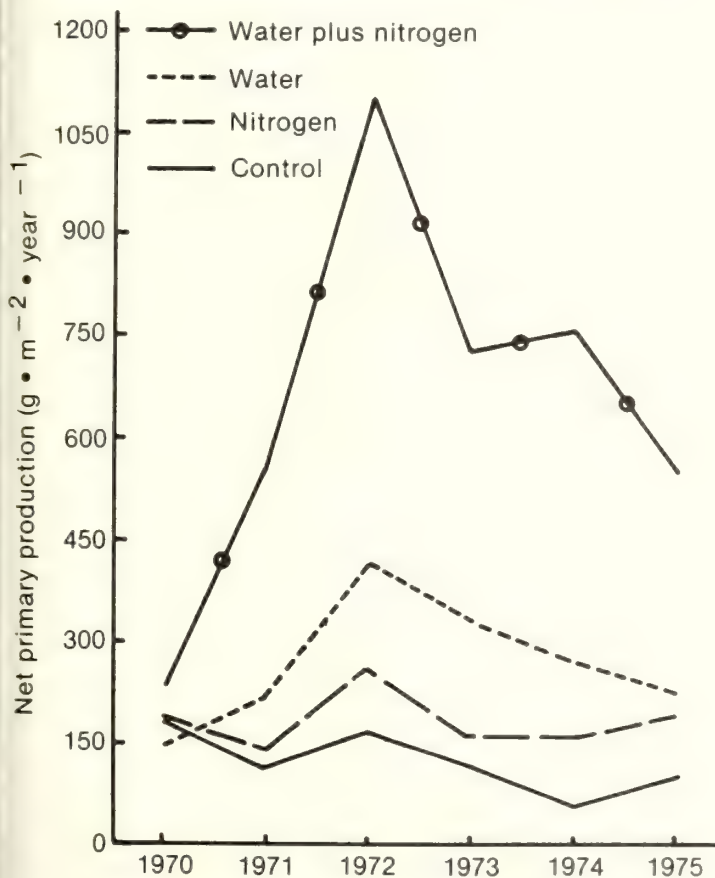


Figure 4.—Aboveground net primary production for water and nitrogen stress experiment, 1970-1975, shortgrass prairie community, Colorado. (Adapted from Dodd and Lauenroth 1979.)

nutrients, and increase nitrogen by stimulating soil bacterial mineralization rates (Sharrow and Wright 1977). The new growth following fire is more palatable to both livestock and wildlife. The species composition of forage can be enhanced following fire to provide increased forbs and palatable, available browse through resprouting.

In general, the detrimental effects of fire on forage production are not serious enough to counteract beneficial ones. Some forage species cannot tolerate the high temperatures found in many fires, resulting in high mortality (Daubenmire 1968); a good example of such a species is *Festuca idahoensis* (Blaisdell 1953).

Specific responses of forage production to fire in various regions of the country have been documented in numerous publications. For example, Wright and Bailey (1980) have written an excellent review of the literature on fire ecology in the Great Plains in which dynamics of both species composition and production on the tallgrass, mixed-grass, and shortgrass prairies are synthesized. Wright (1972, 1978) also reviewed the literature on forage response to fire in shrub communities throughout the United States and in the Rocky Mountain ponderosa pine zone. Lewis and Harshbarger (1976) discussed effects of burning in the Southeast.

The responses of forage species to fire, as expected, are affected by interactions with other environmental factors. For example, in the Southeast, Duvall (1962) found that differential grass production on burned versus unburned pastures depended greatly upon grazing intensity; on closely cropped pastures, other factors, such as increased light, compensated to provide increased growth (fig. 5).

In a simulation of prescribed burning impacts on the tallgrass prairie, Parton and Risser (1980) predicted that triennial spring fires would increase NPP by 9% to 10% while decreasing the amount of litter, production of cool season plants, and nitrogen balance. The authors further concluded that annual burning would have the short-term benefit of increasing NPP even more, especially on grazed pastures, than burning once every 3 years; however, its long-term effect would result in decreased NPP because of greater nitrogen losses.

Effects of Animals on Forage Production

An initial approach towards developing a model or other technique to predict forage production might logically be to consider grazing and browsing animals only as receivers of energy in terms of secondary production. Feedback mechanisms of the grazing animal affecting NPP, under such conditions, would receive little attention. In fact, however, the primary consumer can have a substantial influence on forage production, both directly and indirectly. Moreover, in terms of plant response, the effect may be either negative or positive (or both), depending upon the situation.

Until the 1970's, the prevailing belief among ecologists and range scientists was that grazing only suppressed NPP of forage plants by removing photosyn-

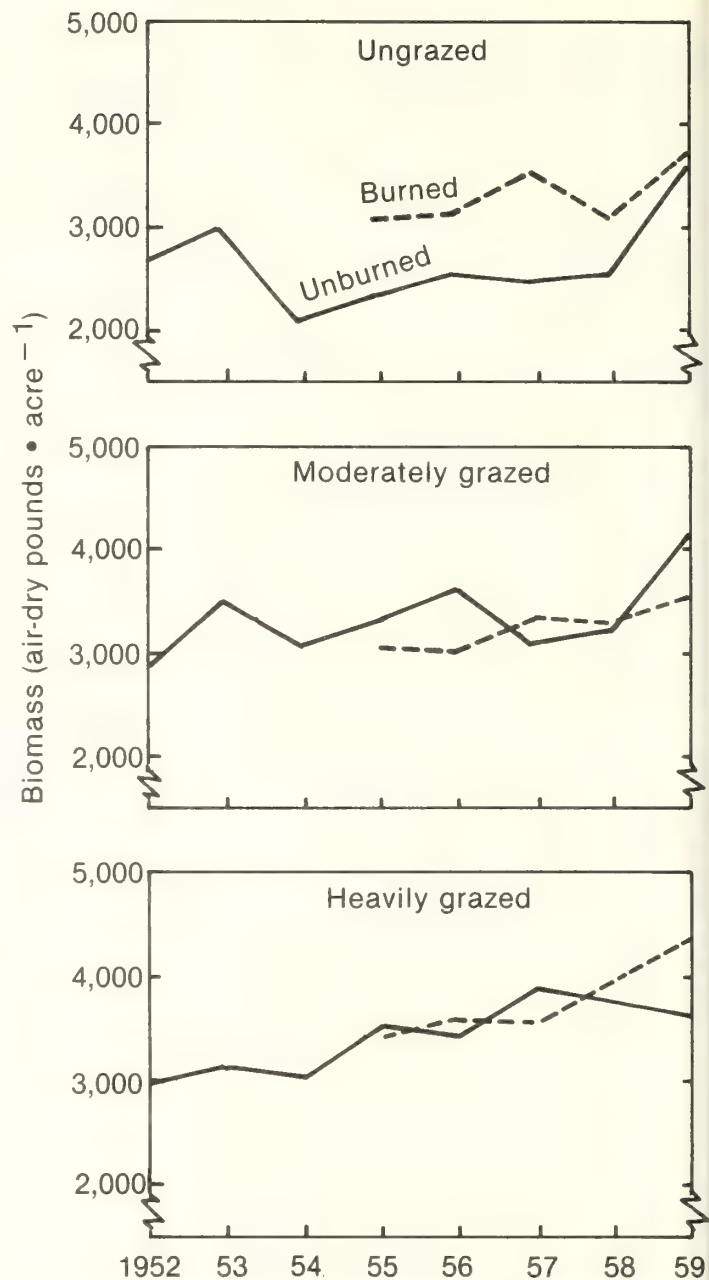


Figure 5.—End-of-growing-season biomass of Louisiana *Andropogon* grassland under three grazing intensities with and without burning. (Adapted from Duvall 1962.)

thetic tissue. The mechanisms for long-term decreased growth under these conditions were shown to be related to decreased vigor (Johnson 1953) resulting from a loss of carbohydrate reserves, which made preferred (i.e., defoliated) forage plants less competitive, especially during the critical, early spring growth period (fig. 6) (Cook 1966). To a lesser extent, early heavy grazing can also be detrimental to forage growth by causing a reduction in plant N, which inhibits development of axillary buds of some grasses, such as *Panicum virgatum* (Beaty et al. 1978). In 1963, Jameson extensively reviewed the literature relating to how plants respond to foliage removal, but his paper pertained only to the ways NPP is reduced by grazing.

A recent paper (Lacey and Poolen 1981) summarized the results of 12 previous studies evaluating the response of herbage production to moderate grazing. Its authors demonstrated empirically that moderate grazing suppressed NPP in almost every case, by an average of more than 30%, if the studies are considered collectively. They concluded, however, that ungrazed pastures would not continue to increase in relative forage production if nonuse persisted beyond 4 to 7 years, the time frame of the studies upon which they reported.

Ultimately, forage production on rangeland also decreases in response to grazing pressure by changing community species composition. Such a process, called retrogression (Stoddart et al. 1975), was recognized and described very early in the history of ecology (Sampson 1919) and led to the concept of range condition based on classification of forage plants into three categories—decreasers, increasers, and invaders (Dyksterhuis 1949). Plants increase or decrease in abundance primarily in response to differential grazing pressure resulting from forage preference or selectivity. The literature on forage preference and its quantification have been reviewed by Krueger (1972) and Arnold (1981). The classical relationship between the abundance of decreasers, increasers, and invaders is depicted in figure 7. Consequently, the ecosystem process of energy flow, regarding NPP of forage plants, is tied closely to the synecological concept of successional state.

Few of the ecosystem models developed to simulate energy flow consider a successional-varying vegetation state, except in terms of arbitrary abundance units (Bledsoe and Van Dyne 1971). Whittaker (1975) reported

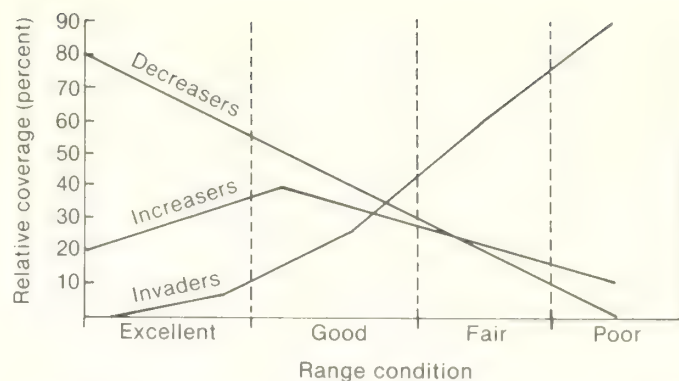


Figure 7.—Proportional relationship among decreasers, increasers, and invaders as range condition goes from excellent (i.e., climax or near-climax) to poor condition (pioneer community). Note that invaders are not part of the climax community. (Adapted from Dyksterhuis 1949.)

on an unpublished study by Holt and Woodwell, on the Brookhaven forest of New York, that predicted total NPP during succession (fig. 8), and Kellomäki et al. (1977) used a modeling approach to estimate annual production of *Vaccinium* spp. in response to succession in Finland. Other than these, little has been reported.

The literature on the theoretical relationship between productivity and succession has been reviewed by Odum (1971). He postulated that net community production should approach zero, because of the convergence of gross production and respiration rates, as a community nears climax (fig. 9). Odum's hypothesis seems better suited for forest ecosystems, with their large standing crop levels, than for rangeland, however. On rangeland, one would expect NPP of forage species to increase during succession, with a leveling at late seral stages and perhaps a slight decline at climax. The response would more likely be a function of management practices, such as grazing intensity, than of succession. In addition, the palatability and availability of what is produced must override the strict interpretation of NPP in the evaluation of this process on rangeland.

In addition to the depressant effect on NPP, grazing can act to stimulate increased forage production under some conditions. For example, warm-season rhizomatous and stoloniferous grasses of the true prairie and Southeast have increased their photosynthetic rates by up to three times as a result of close cropping, possibly because of increased crown light intensity (Beaty et al. 1977). This response is interrelated with nutrient availability, which means that the grazing factor must be considered with fire and fertilization.

Removal of shoots by grazing affects plant hormone balance, which can also result in initiation of new shoots and enhanced growth rates. Several authors (Reardon et al. 1972, Dyer and Bokhari 1976) have suggested that such growth is at least partly caused by the presence of thiamine in the animal saliva being transferred to the shoot, then translocated to the roots, where it apparently stimulates metabolic activity. Thiamine, a member of the vitamin-B complex, normally is synthesized in leaves; it has been called a root hormone, because it appears to be necessary for root meristematic devel-

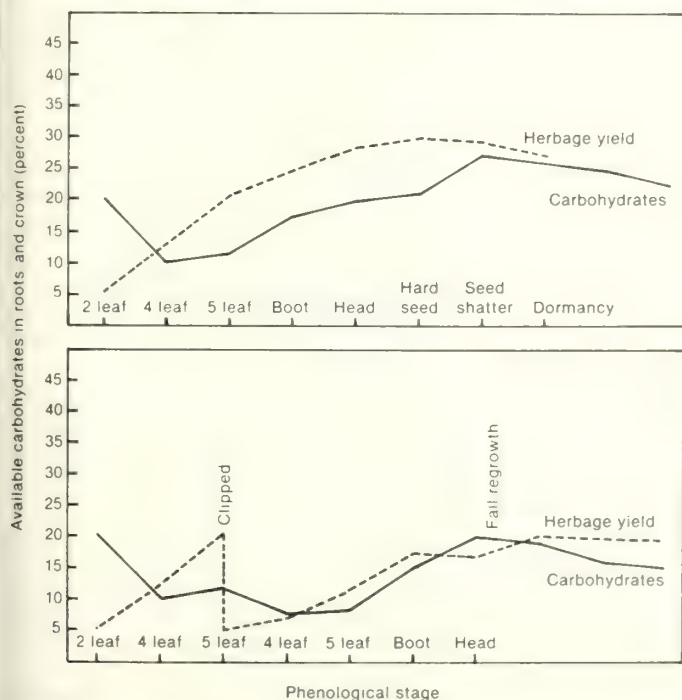


Figure 6.—Carbohydrate balance and herbage yield of a typical grass during its phenological development—(A) unaffected and (B) as affected by clipping. (Adapted from Cook 1966.)

opment (Sosebee 1977). Other recent experimental evidence, however, supports the null hypothesis that saliva from grazing animals either contains no growth regulators or, if hormones are present, does not stimulate top or root growth or tiller production (Detling and Dyer 1981).

Although the interactions between NPP of forage plants and the herbivores that feed upon them are complex and difficult to describe, much less quantify, field experiments do support the hypothesis that grazing can stimulate forage plant growth. For example, Vickery (1972) found NPP of a pasture in New South Wales, Australia, to be greater at a stocking rate of 20 sheep per hectare than at either 10 or 30 sheep.

Generalizations on the interactive relationships between NPP and forage utilization are tenuous; nonetheless, some judgments are possible. First, on an overall basis, herbivory tends to have a negative effect on plant growth, reproduction, and survival. Second, even if clipping warm-season sodgrasses enhances NPP under the right conditions (Hazell 1965), such is not the case for cool-season bunchgrasses (Wilson et al. 1966), especially in xeric environments (Cook et al. 1958). Clipping also depresses NPP of forbs (Julander 1968). The effects of browsing on shrubs have received less attention than have grazing effects on grasses, but the available evidence reinforces the same general response. Browse growing in moist environments appears to be somewhat stimulated by a reasonable level of utilization at certain phenological states (Lay 1965), but desert shrubs decrease in NPP under the influence of browsing (Cook 1971).

Belowground consumers (i.e., micro and macroarthropods, nematodes, etc.) have been the subject of only a small fraction of the total research effort into herbivory as a process affecting NPP or other ecosystem functions. Nonetheless, evidence exists that belowground herbivores may consume more biomass than those aboveground (Coleman et al. 1976). The loss of roots and other belowground plant material to consumers may even impact upon aboveground NPP to a greater degree than might be expected from its own magnitude (Chew 1974). For example, a recent laboratory study (Detling et al.

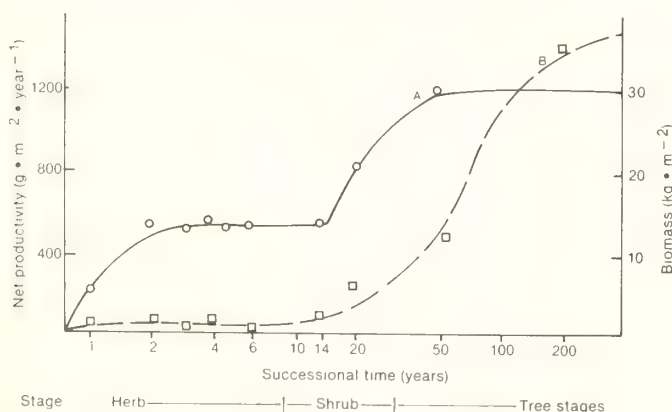


Figure 8.—Net primary productivity (A) and biomass (B) during succession in the Brookhaven oak-pine forest, New York. (Adapted from Whittaker 1975, originally presented in B. Holt and G. Woodwell, unpublished.)

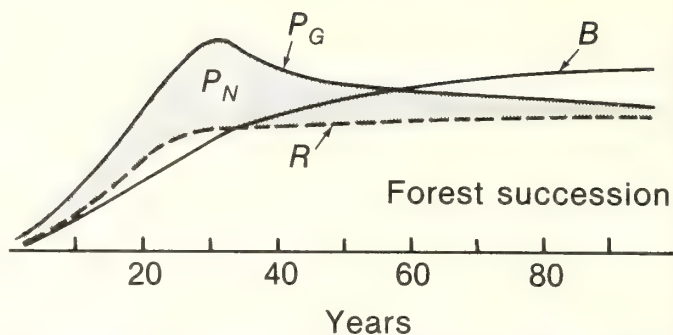


Figure 9.—Net community productivity (P_N = shaded area) of a forested ecosystem in relation to gross community productivity (P_G), respiration (R), and biomass (B) during succession. (Adapted from Odum 1971, originally published in Kira, T., and T. Shidei. 1967. Primary production and turnover of organic matter in different forest ecosystems of the western Pacific Japanese Journal of Ecology 17:70-87.)

1980) demonstrated that crown and leaf biomass of *Bouteloua gracilis* decreased approximately 20-25% following a moderate degree of root clipping, primarily in response to a 50% reduction in tiller production and increased carbon allocation to the clipped roots.

From a resource management viewpoint, the importance of belowground consumer-forage NPP relationships is questionable because abundance levels of the former are extremely difficult to monitor, much less manipulate. Perhaps much of the difficulty in using such relationships to predict NPP will result from this inventory problem.

Influence of Land Management and Use on Forage Production

In the past 100 years, humans have increasingly become manipulators of ecosystems rather than merely creatures in them. For this reason, a discussion of their ability to control forage production is appropriate. Although the question of land use may be more properly an economic one, it does have ecological implications.

The production of forage within a given area can be modified by land managers and other decisionmakers in different ways:

1. Production can be increased by altering the environmental factors affecting plant growth, such as water (irrigation), nutrients (fertilization, fire), and light (harvesting, fire).
2. Forage production can be increased by causing a change in community composition, whereby existing species are replaced by others that are more productive, more palatable, or more usable. Such alterations can result from management on an agronomic basis (plowing and seeding) or an ecological basis (using range management techniques to shape the direction of natural succession or retrogression). Moreover, such replacements of community composition with more productive forage species are frequently a spinoff from other management objectives (e.g., noxious weed control, improvement of riparian habitat, forest harvest practices).

3. Effective forage NPP can be increased by using management tools to make what is produced more available. In this case, actual productivity is not altered, but the amount of biomass available for consumption by grazing animals increases. Range managers have accomplished this by using grazing systems to concentrate livestock, which causes more uniform levels of utilization within a pasture, and by implementing range improvements to create primary range out of secondary range. Primary range is that part of the suitable range that livestock naturally prefer or, under management, will use first. Normally, it is readily accessible and has available water. Ordinarily, primary range areas will be grazed to allowable levels or be overused before other parts of the range are used to any great extent. Secondary range is that part of the range that is suitable for livestock use but is used very little or not at all because of lack of accessibility, lack of water, management system, or a combination of these. It should be noted that grazing systems, if successful, often serve the dual purpose of increasing actual forage NPP through succession and effective production as outlined above. Improper management, obviously, can result in reductions of forage NPP through decreasing range condition (retrogression) and grazing programs that allow ineffective utilization.

4. The available amount of forage produced within a given area can be significantly reduced or increased by changes in land use. The use of rangelands for livestock production is, perhaps, the most extensive form of land use, with the possible exception of dispersed recreation. Shifts and growth in populations have led to a creeping encroachment onto range and pastureland by suburban growth, expanding transportation systems, and other forms of more intensive land use (Love 1970). This loss of forage production could be somewhat offset by shifts from cropland and forests to pastureland.

The first of these four areas, altering environmental factors, has already been discussed. The others require further elucidation.

People involved in grazing systems and range improvements have gathered a wealth of experience; however, few generalizations have been published or are generally available. Van Poollen and Lacey (1979) concluded that, on an overall basis, forage production increased 13% when grazing systems rather than continuous grazing were used, and approximately 30% when grazing intensity decreased for a given system. Variations were large among the various grazing regions in the United States, however. They varied from large increases in the Pacific Northwest and Texas Rolling Hills to no significant difference (or actual production losses) in the northern and central Great Plains (fig. 10).

In another review, Herbel (1971) found grazing systems to be detrimental in the California annual grassland and only moderately effective in the Pacific bunchgrass region. He hypothesized that improvement of bunchgrasses depends on their restoration of vigor

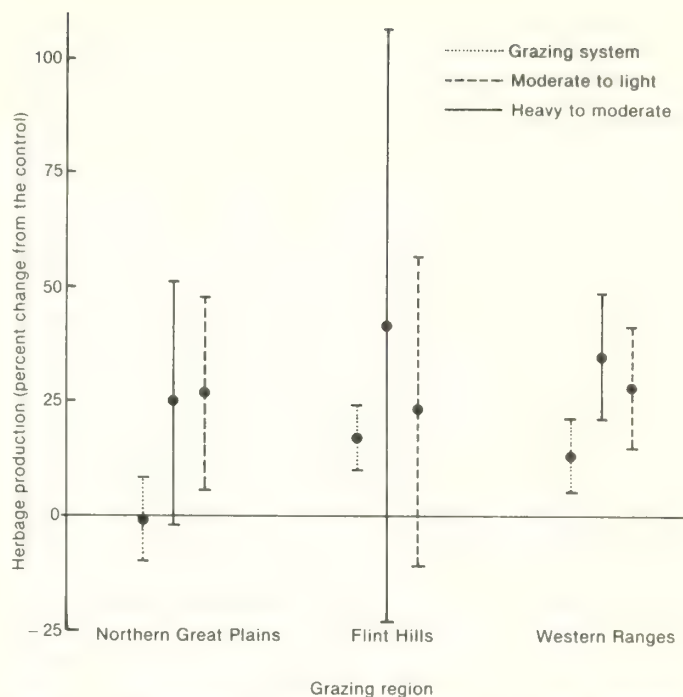


Figure 10.—Response in herbage production for two grazing regions and the western ranges under change in grazing system (from continuous use to rotation system) and grazing intensity (heavy to moderate, moderate to light). Brackets indicate 95% confidence interval. (Adapted from Van Poollen and Lacey 1979.)

and ability to produce seed. The concept of rest-rotation grazing systems has been explained by Hormay (1970).

The response of forage NPP to range improvements is extremely varied and unpredictable. It is a function of several variables, including the kind of improvement, site factors, climate, and initial vigor of the desirable forage species. On a given site, the response to specific range improvements has historically been ascertained by field experiments. Aside from predicting responses from fertilization and irrigation, little in the way of modeling has been accomplished in this area. Moreover, within localized areas, the effects of range improvements can be profound. For example, Hull and Klomp (1974) reported a threefold increase in crested wheatgrass production after sagebrush control in southern Idaho (fig. 11).

On a regional or national basis, however, the influence of range improvements on forage production has been handled more suppositionally, often being based on expected long-term trends of livestock. A potential notable exception is the Grant County (Oregon) Evaluation Study, a 10-year federal, state, and private cooperative program designed to ascertain, among other goals, the long-term effects of improvements on forage production, at least for the Blue Mountain region. This carefully designed project may provide the necessary information to build predictive models on a regional basis. Initial results indicate that large increases, exceeding an order of magnitude, in forage production are possible under a coordinated program of range improvements² (fig. 12).

²Personal communication with Arleigh Isley, Grant County Extension Agent, John Day, Oregon.

It is unlikely, however, to expect the same level of intensive range improvements over large areas in the future, primarily because of environmental concerns and costs. Vale (1974) estimated that only 10-12% of the 40 million acres of western lands dominated by sagebrush have undergone some kind of conversion treatment to enhance grass production; further large-scale projects appear improbable because of fears that sagebrush eradication is detrimental to wildlife.

The last factor, changing land use, has been shown in the past to have the potential for creating large changes in forage production at the national level and, in some areas, the regional level. Long (1974), for example, reported on a study that showed that more than 1.6 million ha of grasslands were converted to cropland in 1974 alone. Cropland, which occupies about 25% of the conterminous United States and can be quickly converted from grassland in some areas in response to favorable market conditions, should be envisioned as the most likely repository of rangeland. Alternatively, cropland can be an important source of replacement land for natural forest and rangeland (Klopatek et al. 1979).

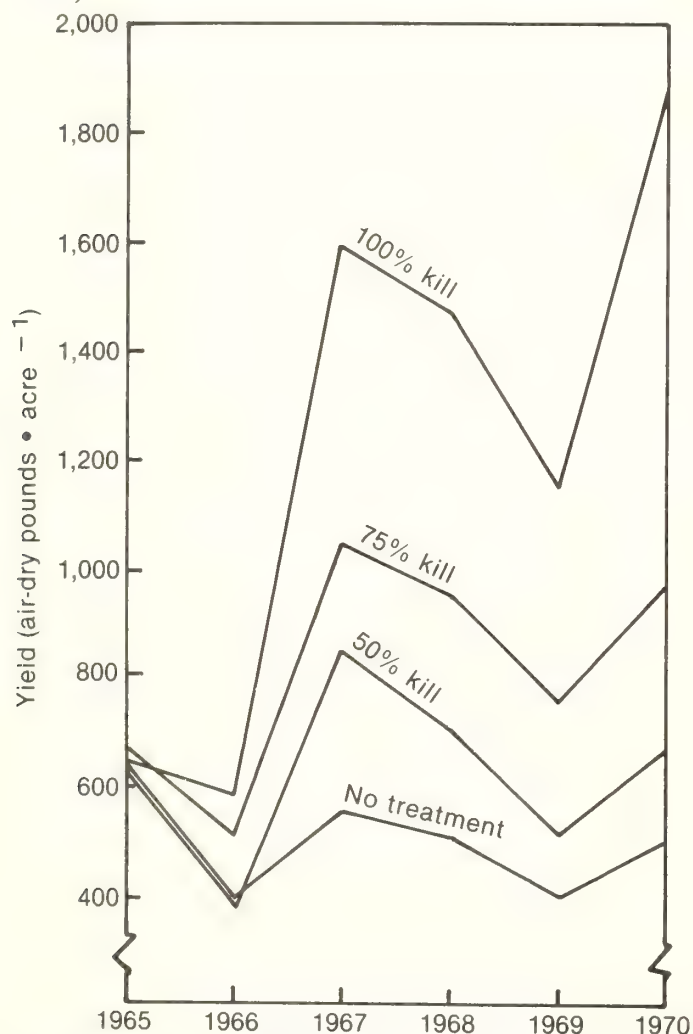


Figure 11.—Yields of crested wheatgrass under four degrees of sagebrush control at Holbrook, Idaho, 1965-1970. (Adapted from Hull and Klomp 1974.)



Figure 12.—Crested wheatgrass seeding in Grant County, Oregon. Forage production has been increased over 100-fold in less than 5 years. (Photo courtesy of Arleigh Isley, Cooperative Extension Agent, Grant County, Oreg.)

Other evidence indicates that land area in cropland has not significantly varied in recent years. According to Clawson (1979), U.S. cropland peaked in the 1920's at about 205 million ha and has stabilized at about 185 million ha in the last 30 years. Klopatek et al. (1979) found that vegetation types which are alterable to cropland have already been nearly completely so changed, and vegetation types that have mostly retained their natural state are least likely to undergo future changes because of rough topography or federal ownership. Both Clawson and Klopatek seem to conclude, then, that large shifts in land use are unlikely in the foreseeable future.

Schertz et al. (1980), addressing the farming outlook for this country, concurred with Clawson (1979) on the present stability of crop acreage nationally; however, he recognized that somewhat offsetting regional shifts are also taking place. Concurrent regional shifts in the U.S. range and pastureland base could significantly affect forage production potentials for the country as a whole because of differences in potential production.

The foreseeable future alluded to above by Clawson (1979) and Klopatek (1979) may extend only a short period ahead. At a recent symposium, Crosson (1979) estimated that an additional 25 to 30 million ha of cropland will be required to meet projected food demands by the end of this century, and that these tracts must come from nonagricultural instead of set-aside lands. Other sources (Dideriksen et al. 1977, Brewer and Boxley 1980) indicate that somewhere between 15 and 31 million ha of noncropland (pasture, range, forest) have a high potential for cropland development and from 14 to 37 million ha have a medium potential. Less than a million hectares, however, evidently has the potential to be quickly converted without major outlays for soil preparation or water facilities (Shulstad and May 1980).

Overall, it may be concluded that future effects of land-use conversion on forage production are not predictable, but the potential for change in either direction, given the growing world population and the international nature of agriculture and politics, is certainly feasible.

Forage Production Models

Models are, by definition, abstractions or simplifications of systems (Hall and Day 1977). Their value lies in their ability to simplify complex systems (e.g., the real world) by leaving out some information while including only those elements and interrelationships that are thought to be important in determining cause and effect. Thus, models do not represent systems completely and cannot answer all questions about the structure and function.

Characteristics of Simulation Models

In ecology, simulation models express the dynamics of ecosystems by evaluating their change of state. The state of a system is embodied in the condition of its state variables or defined components (Patten 1971). In the most common form of simulation models, the state variables are called compartments, and the model is a compartment model. The interrelationships among the state variables in compartment models are usually expressed in the form of a series of differential or difference equations. If differential equations are solved numerically (e.g., Euler and Runge-Kutta methods), as is normally done in compartment models, then little difference exists between the two mathematical forms. The system behavior is determined by simultaneously solving the series of equations. Numerical approximation solutions are used, because analytical solutions of ordinary differential equations are difficult to essentially impossible for linear equations, and impossible for nonlinear equations.

Whether or not the equations describing ecosystem behavior must be linear (i.e., being other than first degree in the case of differential equations) has been an area of controversy among ecosystem modelers. One group believes that the dynamics of natural ecosystems are ostensibly linear, even though they are driven by processes which are nonlinear (Patten et al. 1975), and that the large assemblage of linear systems theory developed in engineering which can be applied to analysis of linear models (Waide and Webster 1976) makes such an approach worthwhile.

Proponents of nonlinear models base their argument on the premise that mathematical models should be analogous to the real world system being modeled, which is generally conceded to exhibit nonlinear characteristics (Bledsoe 1976b). In addition, Innis (1975) argued that, conceptually, biologists participating in the modeling of whole systems perceive relationships in nonlinear terms; forcing the discussion in other directions would result in the loss of the contribution biologists could otherwise make. There are several inherent problems associated with nonlinear models, such as the lack of algorithms for sensitivity analysis and undesirable intrinsic characteristics (e.g., those associated with steady state) (Patten et al. 1975); however, supporters of nonlinear models believe these problems subordinate to those associated with linear models.

Models may also be classified as either mechanistic or descriptive. In mechanistic models, equations express the causality affecting each state variable's behavior; in the latter, the equations merely describe it. Systems ecologists agree that, when possible, a model should be mechanistic (Hall and Day 1977), but these models require an understanding of the autecological bases of the state variables' responses to inputs.

Models are also categorized as being deterministic or stochastic (Patten 1971). Models that produce unique outputs to a given set of initial conditions are deterministic in nature; those that produce varying outputs following some distribution of values because of some level of uncertainty are stochastic.

Special techniques, called Monte Carlo, are used to induce statistical variations in simulation models (Breipohl 1970). Using Monte Carlo techniques in simulation models often requires a substantial amount of computer time. Kowal (1971) has stated that, in the case of linear deterministic models, probabilistic inputs have a good potential for imitating dynamic ecosystems. Because of their applications in electrical engineering (i.e., "noise" and "random signals"), linear deterministic models are well validated.

Forage Production Models

Early forage production models were simple, descriptive, and deterministic in nature (Clary 1964); however, more elaborate models predicting primary production have been developed in recent years. Van Dyne et al. (1978) has indicated that models are related to the hypotheses being addressed by it (i.e., hypotheses concerned with natural resource management must be specific to the particular ecosystem(s) involved). Such hypotheses are developed by experienced scientists, based on their own backgrounds and knowledge of the literature. Models so developed, for example, might be able to address hypotheses on forage production as affected by grazing intensity and season of use, insect outbreaks, irrigation, fertilization, fire, and range improvements (Van Dyne et al. 1978).

An interdisciplinary strategy, such as described by Van Dyne (1966), has been shown to be necessary to accomplish the kinds of goals that go with a modeling approach to describing dynamics of natural systems. Interdisciplinary techniques require the use of a common vocabulary and a high level of coordination among team members.

According to a recent Forest Service problem analysis (USDA Forest Service 1981), the state of the art in ecological analysis is currently best expressed in terms of either interdisciplinary teams (Delphi process) or simulation models, with models holding the most promise for predicting impacts of resource management on forage NPP, as well as other resource outputs. A brief review of representative ecosystem models used in estimating forage production is given in table 1. Van Dyne and Abramsky (1975) provide another overview of models simulating ecosystem productivity. In addition,

Table 1.—Listing of recent simulation models in which forage production is an integral component

Reference	Type of model	Inputs and/or driving variables	Remarks
1. Kelly et al. (1969)	Seven-compartment model of NPP ¹ of <i>Festuca</i> and <i>Andropogon</i> .	Growth is a function of available solar energy based on a sine function.	Primarily this model was designed to simulate transfer of biomass to roots, standing dead, and litter, once NPP had "occurred."
2. Ross et al. (1972)	Simplified model of grass-legume sward.	Growth of legume based on light intensity in canopy and growth of grass upon both light intensity and available N.	Potential photosynthesis nonlinear functions of light intensity and LAI ² growth expressed in terms of LAI.
3. Singh (1973)	Six-compartment linear model of herbage dynamics of tropical grasslands.	Total production based on time-varying transfer coefficients.	See remarks for Kelly et al. (1969). Model structure is very similar.
4. Bledsoe (1976a)	Total systems model (PWNEE) with some 40 state variables. Based on first-order, ordinary, nonlinear differential equations.	NPP is a result of equations for photosynthesis, translocation, respiration, and death. Photosynthesis is a function of light intensity and duration, temperature, soil water, nutrient supply, and tissue aging.	One of first models in which primary production is based on mechanistic parameters. Site specific to the shortgrass prairie.
5. Noy-Meir (1978)	Simple model of primary and secondary production in a seasonal pasture based on system of linear differential equations.	Plant growth rate is a linear function of biomass less respiration.	Equations are simple enough to allow for exact analytical integration.
6. Brockington (1978)	Model of sward production based only on soil water deficit at two levels (topsoil and subsoil).	Soil water deficit is a function of meteorological data for rainfall, irrigation, and potential evapotranspiration.	Soil water deficit is the stress beyond field capacity.
7. Sauer (1978)	Submodel of primary production as part of total systems model (ELM) of the North American grasslands biome. About 30 compartments depicting carbon flow through warm and cool season grasses, forbs, shrubs, and cactus. ELM is nonlinear and based on difference equations.	NPP is equal to GPP ³ less respiration. GPP is a function of soil water, air temperature, nitrogen, phosphorus, light intensity, and phenology. Other factors determining biomass dynamics of primary producers include grazing, translocation, and death.	ELM is similar to PWNEE (Bledsoe 1976a) as a mechanistic model. It is somewhat more suitable for general use because it utilizes a simulation language (SIMCOMP) ⁴ rather than FORTRAN, with parameters for several grassland types instead of being specific to the shortgrass prairie.
8. Cale (1979)	This model (LINEAR) is a total systems model of the shortgrass prairie similar to PWNEE (Bledsoe 1976a) except for a greater number of belowground and lesser number of aboveground state variables. LINEAR is based on a system of time-varying linear differential equations.	NPP is assumed to be 66% of GPP. GPP is a function of light intensity and duration, temperature, and evapotranspiration.	LINEAR was originally developed as a class project (Patten 1972) to show that a linear model could accurately predict biomass dynamics of a shortgrass ecosystem. The IBM simulation language CSMP was used in this study.
9. Detling et al. (1979)	Intraseasonal model of blue grama production. Contains 14 compartments. Mechanistically simulates carbon allocation in early spring (from crown) and later (from leaves).	Carbon flow is a function of temperature, soil water, light, and nitrogen.	Designed as an improvement to Sauer's (1978) producer submodel in ELM (see above).
10. Irwin and Peek (1979)	Regression model of shrub production following logging in a closed forest of the northern Rockies.	The regressions predicting production are based on time since tree removal and overstory remaining.	This model was designed to couple with a timber growth model titled PROGNOSIS (Stage 1973).

Table 1.—Listing of recent simulation models in which forage production is an integral component—Continued

Reference	Type of model	Inputs and/or driving variables	Remarks
11. Fick (1980)	Pasture production submodel (CANPAS) of a whole farm simulation model. CANPAS is a differential equation model with six compartments.	Equation simulating NPP is a function of potential NPP and the difference between a ceiling biomass and an actual biomass. Potential NPP is related to six abiotic and biotic variables.	The model predicts yield from a series of 16 differential equations. The CSMP simulation language is used.
12. Grant and French (1980)	A model designed to simulate the functional role of small mammals in grassland ecosystems. Composed of three submodels, one titled "Biomass." Biomass sub-model has 12 state variables.	NPP is a function of soil water, topsoil N, temperature, and small mammal activity.	The model is based on difference equations and makes use of the SIMCOMP simulation language.

¹NPP is net primary production.

²LAI is leaf area index.

³GPP is gross primary production.

⁴For a discussion of SYMCOMP, see Innis and Gustafson (1978).

Van Dyne³ has summarized models used in simulating animal production systems.

Because there have been no models explicitly designed to predict regional forage production on the basis of abiotic driving variables, the mechanisms necessary to do so on such a large scale are not known. It is logical to expect, however, that regional models will be of relatively low resolution and will rely heavily on seasonal precipitation patterns as a driving variable. Wysong and Fisser (1974) published statistical models describing perennial grass production in western Wyoming, in which spring precipitation and the previous year's winter-plus-spring precipitation accounted for the most variation in production. Other important factors, especially on drier sites, were depths of the A-horizon and root zone. Modeling appears to offer the best long-term approach to attaining the integrated socioeconomic-level information required for regional and national resource planning. It may well be in this area that opportunities to advance the state of the art will be most beneficial.

Forage Production as a Factor in Secondary Production

Animals must obtain from food all of the chemical compounds necessary to sustain life and carry out their metabolic needs. The concept of trophic levels and food chains, which explains this process in ecosystems, has been an accepted principle of ecology and energetics for many years (Lindeman 1942); nonetheless, the uptake and turnover of energy at secondary levels is not yet clearly understood (Darnell 1968). In the 1970's, the situation started to change, primarily as a spinoff of expanding research on the analysis of primary production. The International Biological Program (IBP) provided impetus to this effort, especially for nondomesticated animals (Scott et al. 1979).

³Systems analysis in analysis of animal production systems. Invited paper on modeling for IV World Conference on Animal Production. Buenos Aires, Argentina. August 1978.

The relationship between livestock production and the quantity and quality of available forage has received detailed study for the past 30 years. For the most part, however, this level of knowledge has not been used in range management at state or federal levels; nor has there been a requirement to do so, because the "standard" product of the range is an animal unit month, which has been assumed to be the same, regardless of the variables affecting its worth.

On federal lands the price of an AUM is constant regardless of the value of the forage. Factors which should affect forage value are numerous, but include quantity, quality (primarily protein concentration), topography, distance from water, distance from roads and other grazing lands, presence of predators or poisonous plants, and improvements. On private lands, such variables are generally accounted for in the market price. It is beyond the scope of this paper to examine the AUM and secondary production in detail; nevertheless, a brief overview of the relationships between forage quantity (energy) and forage quality in comparison to secondary production (particularly red meat production of livestock) is appropriate.

Energy Requirements of Grazing Animals

As previously discussed, ecological efficiency of ecosystems relates to the efficiency in which solar radiation is fixed by autotrophs, and, thereafter, transferred to herbivores and carnivores.

Energy taken in by foraging animals is used for maintenance, weight gain, milk production, fetus development, hair and wool growth, and respiration (Cook 1970). Efficiency of conversion at the consumer level involves the integration of numerous genetic, physiological, and environmental factors.

Energy intake by grazing animals has been divided into several components (Cook 1970). Gross energy is the

energy value (calories) of ingested forage. Part of this energy remains undigested and is excreted from the animal after passing through the alimentary tract. That which becomes digested is termed digestible energy. If energy losses in the form of urine and methane (gas) are subtracted, the remainder is termed metabolizable energy. Deleting energy lost in heat of respiration, which varies according to activity level, workload, etc., leaves a remainder called net energy. Net energy defines the level of energy available to the animal for body maintenance (replacing cells that die) and secondary production.

From an energetics viewpoint, secondary production in grazing or browsing animals includes production of red meat, fat, bones, milk, and wool (Cook 1970). This somewhat contravenes the colloquial delineation of red meat production often used in range management.

The use of digestible energy as a measure of energy content of forage is useful in a feedlot situation; however, in a rangeland ecosystem, such a measure can overestimate available energy. Many range plants, especially browse species, are relatively high in essential oils and fats, which tend to be digested but eliminated in the urine. Consequently, metabolizable energy is deemed to be more suitable than digestible energy (Cook 1970). For example, Cook and Harris (1968), in a study of nutritive value of seasonal range plants, found forage species on desert winter ranges to be somewhat lower in gross energy (4,370 versus 4,125 kcal·kg⁻¹) than those on seeded spring range and summer range. Moreover, less of that energy (39% versus 48%) represented metabolizable energy. Van Dyne (1969) reviewed the literature on the techniques for determining the energy content of forage plants.

To develop an energy budget model for secondary production of grazing or browsing animals, one must know the energy requirements for various metabolic activities (e.g., maintenance, activity, fetal growth, body gain, wool growth, respiration). Cook (1970) provided an excellent review of the literature on this subject. Of course, the animal response to forage energy cannot be described without a reminder that other important plant nutrients can also limit secondary production. These include digestible protein, phosphorus, and carotene (Cook 1970). Perhaps the most important of these is protein.

Protein Requirements of Grazing Animals

About 80% of the atmosphere is composed of nitrogen. Despite the presence of such vast quantities of nitrogen, most plants and all animals cannot metabolize N₂ directly, but rely upon its fixation by microorganisms into usable inorganic form. Because of limited nitrogen availability, productivity at both the autotrophic and primary consumer trophic levels is constrained by nitrogen in many situations. This section examines the relationship between forage quality (defined here in terms of protein content) and secondary production of grazing animals. To comprehend the factors controlling this

interaction, one must first examine the nitrogen cycle as it affects the level and form of nitrogen in forage plants. The influence of nitrogen on the amount of available forage (i.e., NPP) has been previously discussed.

A clear overview of the generalized nitrogen cycle is in the elementary soils text by Brady (1974). Most research into nitrogen dynamics has been conducted on agronomic systems, which tend to be simpler and more completely understood than natural systems. In the last decade, however, several investigators have traced the pathways of nitrogen in natural terrestrial ecosystems, including deserts (West and Skujins 1977) and grasslands (Reuss and Innis 1977, Woodmansee 1978, Jones and Woodmansee 1979). Rodin and Bazilevich (1967) have presented data on numerous ecosystems.

Research has demonstrated that the four plant nutrients most crucial to secondary production of range livestock are protein, phosphorus, energy, and carotene. Of these, the proportion of digestible protein appears to regulate animal gain more closely than any other factor (Cook and Harris 1968). Digestible protein is the protein in consumed feed apparently digested by the animal. Dietz (1970) reviewed different measures of forage quality and their definitions. In relating secondary production to forage quality, one must consider more than just nitrogen levels because of variations in nitrogen digestibility among species, in plant parts, and with time. Crude protein is commonly defined as nitrogen content of forage dry matter multiplied by 6.25; however, nitrogen digestibility varies with several factors, primarily tissue age (Cook and Harris 1968). The percent digestible protein in forage plants varies widely. In general, diets of range livestock in spring contain about 7-11% digestible protein, while, in the fall, this figure declines to 4% or less (Cook et al. 1977). On winter sheep ranges of the Intermountain region, digestible protein can dip below 2% (Cook and Harris 1950).

Not only does digestibility of forage protein decrease with tissue age, but the actual levels of nitrogen, which determine crude protein, decline also, primarily as a result of translocation (fig. 13). This effect is more pronounced in grasses than in browse, probably because nitrogen is translocated to the crown and roots of grasses, while in browse some nitrogen may be stored in the twigs and remain available for consumption.

The compounded net result of decreasing crude protein and its digestibility during a growing season can have a profound effect on secondary production once minimum thresholds are not met. Vavra and Phillips (1980) followed the diet quality of cattle and their resultant change in weight through several grazing seasons on summer range in northeastern Oregon. They found significant fluctuations from year to year, probably because of precipitation pattern influences; nonetheless, in general, crude protein of forage consumed decreased continuously and somewhat proportionally to the nitrogen level of principal forage grasses (fig. 14). In contrast, cattle weight gains maintained a somewhat constant rate for most of the grazing season, ostensibly until forage quality did not meet the animals' minimum needs, after which it dropped rapidly (fig. 15).

Cook et al. (1977) evaluated the response of range animal weight gain to changing digestible protein content of forage, and found an exponential relationship for both cattle and sheep over all seasons of use (fig. 16).

Cook and Harris (1968) proposed recommended levels of energy and digestible protein for range livestock (table 2). If one assumes a digestibility of 70% of the forage consumed in the Oregon study (Vavra and Phillips 1980), the point at which their cattle weight gains started to rapidly decline is in reasonable agreement with the recommended minimum protein level.



Figure 13.—Effects of age on nitrogen contents of several tropical grasses: 1. *Digitaria decumbens*; 2. *Chloris gayana*; 3. *Setaria* sp.; 4. *Sorghum alnum*; 5. *Pennisetum clandestinum*. (Adapted from Simpson and Stobbs 1981.)

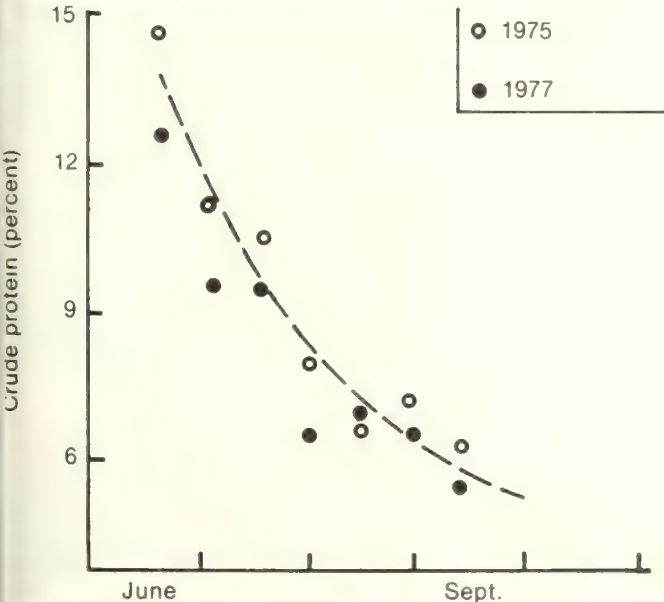


Figure 14.—Crude protein in cattle diets during 2 years for the summer grazing season in the Blue Mountains, Oregon. (Adapted from Vavra and Phillips 1980.)

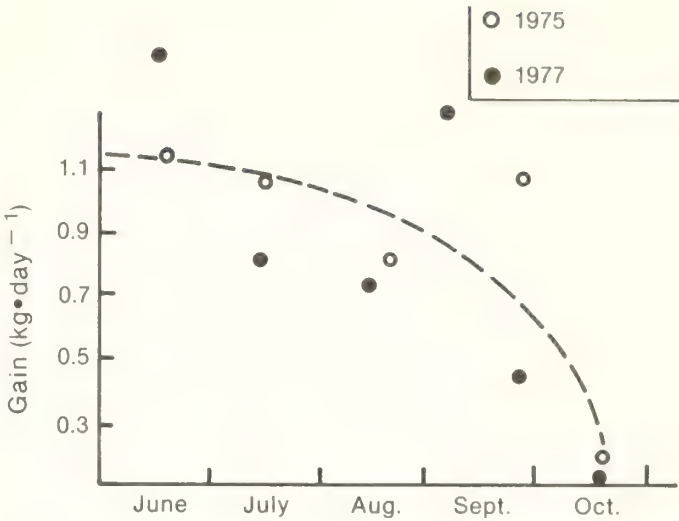


Figure 15.—Average daily weight gain of calves during 2 years for the summer grazing season in the Blue Mountains, Oregon. (Adapted from Vavra and Phillips 1980.)

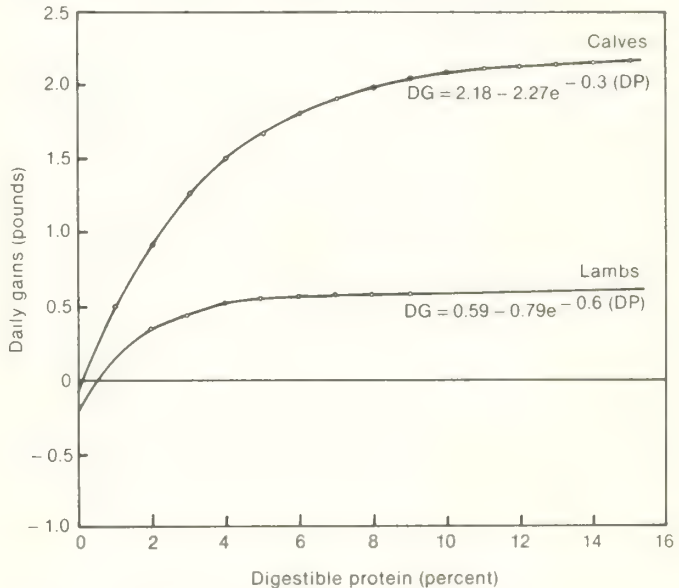


Figure 16.—Predicted average daily gain for range calves and lambs, during spring and summer, based on the digestible protein (DP) content of the diet. (Adapted from Cook et al. 1977.)

Table 2.—Recommended levels of energy and protein for cattle and sheep under range conditions (adapted from Cook and Harris 1968)

Phase of animal metabolism	Digestible energy	Metabolizable energy	Digestible protein
	----- kcal/kg -----		percent
Gestation	1830	1465	4.4
Early lactation and growth	2470	1985	5.4
Late lactation	1940	1545	4.5

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This report is an overview of the biotic and abiotic ecological factors, including the activities of man, that affect forage production on forest and rangeland ecosystems. Also discussed are a review of forage production models, and how forage quantity and quality can control animal production.

Keywords: Forage production, primary production, ecosystem models, energy flow

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Rocky
Mountains



Southwest



Great
Plains

U.S. Department of Agriculture
Forest Service

Rocky Mountain Forest and Range Experiment Station

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United States
Department of
Agriculture

Forest Service

Rocky Mountain
Forest and Range
Experiment Station

Fort Collins,
Colorado 80526

General Technical
Report RM-99



Snag Habitat Management :

Proceedings of the Symposium



June 7-9, 1983

Flagstaff, Arizona

Preface

Some 85 species of North American birds excavate nesting holes, use cavities resulting from decay, or use holes created by other species in dead or deteriorating trees. Such trees, commonly called snags, are similarly important to numerous species of mammals, reptiles, amphibians, and invertebrates. Unfortunately, these snags have often been considered undesirable because they are not esthetically pleasing, conflict with other forest management practices, may harbor forest insect pests, or may be fire or safety hazards. The dramatic increase in demand for fuelwood has further decimated the number of dead trees left standing for cavity-dependent wildlife.

Only recently have resource managers recognized the importance of snag habitat and the problems associated with its management. The majority of cavity-nesting birds -- woodpeckers, swallows, wrens, and nuthatches, to name a few -- are insectivorous, and play an important role in the control of forest insect pests. The concept of this symposium therefore, was to recognize the problem, exchange ideas and solutions, and disperse information among land managers, industry, researchers, resource specialists, and wildlife biologists. The data and ideas presented here are urgently needed to integrate snag habitat

management with other equally valid resource uses and demands.

Rapid publication of these proceedings was due largely to the excellent efforts of the authors (and their typists!) in preparing camera-ready manuscripts. Since papers are being printed as received, each contributor is responsible for the accuracy of his or her paper; opinions expressed by the authors may not necessarily reflect the policy of the U.S. Department of Agriculture.

Many people and agencies contributed to the success of this symposium. Jerry Davis, Greg Goodwin, Gary Bateman, Richard Ockenfels, and Glen Dickens served as the Steering Committee. David Patton was instrumental in involving the Rocky Mountain Forest and Range Experiment Station in publishing the proceedings. R. H. Hamre and Phyllis West compiled the proceedings for publication. Other significant contributions were by Sandra Pinkerton, registration; Peggy Barker, university coordinator; Sandra Walchuk, posters; Richard Ockenfels, program; Jeffrey Brawn, field trip; Arizona State University Student Chapter of the Wildlife Society, audio-visual support; and Ken Byford, promotional affairs.



SNAG HABITAT MANAGEMENT: Proceedings of the Symposium

**June 7-9, 1983
Northern Arizona University
Flagstaff**

**Jerry W. Davis, Gregory A. Goodwin, and Richard A. Ockenfels
Technical Coordinators**

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Welcoming Remarks¹

Bud Bristow²

The Arizona Game and Fish Department is pleased to be a co-sponsor of this Symposium on Snag Habitat Management. That seventeen states, numerous Federal and State Agencies and Universities are represented is testimony to the interest at all levels in snag management.

The Arizona Game and Fish Department has long realized the value of snags to many species of our state's wildlife. For example, over 70 species of birds and mammals use snags on the Coconino Forest. Work done on turkeys by Fred Phillips, one of the Department's Wildlife Managers, focused on the importance of snags as roosting sites. The value of snags to Arizona's cavity nesting birds are well documented.

We are also aware that many of our existing snags may be jeopardized by current commercial timber and fuelwood management practices. Cable suspension logging is starting to cut into resources of snags in canyons and on the steep hills. Improper removal by the public for fuelwood is taking its toll. The Game and Fish Department is not a land management agency and, therefore, is limited to how it can directly affect the management and protection of snags. Currently, we do not have a snag management policy. The Department is, however, moving toward a policy on commercial timber harvest that will increase our involvement in timber

management practices, and will hopefully provide for maximum diversity of age-classes in all forest types.

A term I'm sure we're going to hear more and more is holistic. This concept is old; as old as wildlife management, and as old as a land ethic. It still is not an accepted practice in principle on our public land. It is a term we had better see in use, however, if our resource responsibility, wildlife, is to survive. We must continue to plan and negotiate management methods beneficial to wildlife. Otherwise, we can lose more during this current production-oriented period than we gained in all the accumulated restoration of decades of good management.

Several questions come to mind when snags are considered. The first and most obvious is where will tomorrow's come from? The 12" saw timber cutting cycle?

What are we doing to stop the rapid loss from illegal fuelwood cutting? Are we to have a natural complement of age classes surrounding the snags?

We have the answers we need for most management decisions. Refinement of particulars is desirable, but management won't wait until all the answers are in. We must make a commitment to management of our future snag and old growth resource. Hopefully, this symposium will act as a catalyst to develop a strong interest in snag management at all levels and generate further study.

Again, I wish to welcome you on behalf of the Arizona Game and Fish Department and I look forward to an enlightening and invigorating symposium.

¹Paper presented at the Snag Habitat Management Symposium, [Northern Arizona University, Flagstaff, Arizona, June 7-9, 1983].

²Bud Bristow is Director of the Arizona Game and Fish Department, Phoenix, Az.



Managing Snag Habitats in Southwestern National Forests¹

William D. Zeedyk²

INTRODUCTION

The Forest Service is pleased to participate with Northern Arizona University, Arizona Game and Fish Department, and The Wildlife Society as a co-sponsor of this important symposium on the management of snag habitats.

There is now general recognition that snag habitats are of high importance to a wide variety of wildlife species. Various laws, regulations, departmental and agency policies imply that snag habitats be recognized and managed as a necessary component of forest diversity and to sustain viable populations of native wildlife.

Much information is now available, but much more is still needed to enable the wise management of the snag habitat resource in harmony with other multiple use-sustained yield resources of the forest. This symposium is providing a long overdue forum for exchange of such information and will be valuable to the Forest Service as land management planning continues.

SITUATION

During the course of this symposium, you will learn again and again of the many species of vertebrates that need snags and why they need them. Birds need snags. Mammals need snags. Reptiles need snags. Even fish need snags in the form of down logs imbedded in the streambanks. The facts are well-known and well-accepted among wildlife biologists, foresters, planners, and land managers.

The question is no longer one of need. The question is: What options does the land manager have available for providing adequate snag habitats to meet wildlife management objectives without creating unacceptable impacts on other resource uses? What yield of wood fibre must be diverted annually per unit of area to perpetuate snag dependent wildlife at desired population levels? What are the most efficient ways of providing snag habitats? Can we perpetuate snags without creating unacceptable safety hazards? Can we perpetuate snags without creating an unacceptable insect and disease menace or fire hazard. Do the needs and opportunities vary by ecosystem?

Unfortunately, it is not sufficient to say that snags are necessary and provide useful functions in the managed forest. Maintaining snag habitats diverts wood fibre away from other uses, involves opportunity costs, and drains revenues. Snags, like most products of the forest, are a renewable resource, but their management causes conflicts. The Forest Service is cognizant of the need for snags and is determined to resolve, to the greatest extent feasible, conflicts between snag habitat management and other resources.

SOME PROBLEMS FACING MANAGERS OF SNAG HABITATS

1. Characteristics and attributes of snag habitats vary widely between biotic communities or forest types. Managers need more information on the relationships existing between dependent wildlife species and the dominant tree species characteristic of a particular forest type. Such information can be used to determine the relative importance and identify conflicts with other resource demands. In the ponderosa pine type, for example, one species, the pine, must provide all the needs; but in the gambel oak-ponderosa pine type, a portion of snag habitat requirements can be met by large oaks, releasing some pine volume to meet sawtimber demands.

In the Southwest, there is a considerable volume of information available on snag habitat requirements of cavity nesting species inhabiting the ponderosa pine and mixed conifer types, but relatively little on spruce-fir, aspen, pinyon-juniper, or riparian forest types.

2. Due to the requirements of the National Forest Management Act and the National Environmental Policy Act, there is great emphasis being placed on habitat monitoring. Managers need efficient monitoring systems that will establish and track conditions and trend in snag habitat quality and abundance by forest type and land area. Ideally, snag habitat monitoring systems will be compatible with other resource monitoring activities, and any needed information will be collected in conjunction with other resource inventories.

3. Forest land and resource plans being developed pursuant to the National Forest Management Act and accompanying regulations place a great deal of reliance on the management indicator species concept to predict the effects of alternative prescriptions on wildlife. There is a critical need to test the management indicator species concept to establish beyond reasonable doubt that trends in the status and distribution of selected indicator species are truly representative of the

¹ Paper presented at the Snag Habitat Management Symposium. (Flagstaff, Arizona, June 7-9, 1983)

² William D. Zeedyk, Director of Wildlife Management, USDA, Forest Service, Region 3, Albuquerque, N.M.

snag habitat dependent species they are intended to represent. Management indicator species typically selected for National Forests in the Southwest include such dependent species as pygmy nuthatch, hairy woodpecker, and plains titmouse. Do these species fairly represent the needs of other cavity nesters utilizing snag habitats in their respective ecosystems?

4. An educational program is needed to gain public knowledge and appreciation for the value of snag habitats. While there is increased internal acceptance within the Forest Service of the need to maintain some standing snags and downed logs for wildlife, the public may see this as a poor management practice and wasteful of the fuelwood resource.

5. All efforts to manage snag habitats for wildlife that may result from more enlightened forest management will fail in accessible areas if the now rampant illegal cutting of standing and down woody material for fuelwood is not brought under control. This is perhaps the most urgent threat to snag habitat protection facing land managers in the Southwest. Because trained personnel available for law enforcement are scarce and regulations pertaining to fuelwood possession weak, many snags retained during commercial logging

activities are soon taken illegally after a sale closes.

6. A concerted effort by wildlife biologists, silviculturalists, timber sale administrators, and safety inspectors is needed to develop improved practices for identifying and safeguarding snags and potential snags for retention in sale areas. Many otherwise suitable potential snags are destroyed inadvertently because live cull trees are marked for cutting which might be retained. Isolated snags are felled as safety hazards where they might be retained if included within clumps of unmarked leave trees.

CONCLUSION

There is an established and growing acceptance of the value of snags for wildlife. Managers agree that snag habitats are needed and have a role in the managed forest, but a number of questions need answering. The main question is: What options are available to forest managers to perpetuate snag habitats at acceptable levels while addressing other public issues and management concerns? Hopefully, this symposium will provide some answers and point the way to resolving some of the conflicts inherent in protecting snag habitats in the managed forest.



Snags Are for Wildlife¹

Jerry W. Davis²

Abstract - - Snags provide habitat for many wildlife species. This habitat is used to meet physiological and behavioral needs. Snag habitat awareness and management has improved in the past decade, but problems persist. It is time to implement solutions and to manage snag habitat on a sustained-yield, in perpetuity, for wildlife and the health and viability of the ecosystem.

INTRODUCTION

The statement "snags are for wildlife" may bring several thoughts and impressions to mind.

To some it may appear argumentative or threatening. Others may perceive it as wishful thinking, a condition that should be but is not, or a biological fact. Regardless of the point of view, snags provide essential habitat for wildlife and perform a vital role in the ecosystem.

A SNAG IN THE SYSTEM

My first thought in writing this paper was to use data from the many papers in my files to prove beyond a doubt, to anyone with an open mind, that snag habitat and snag-dependent species are valuable and worth saving. The proof of purpose and value of snags and wildlife in the system, however, has already been well documented.

Snags provide essential habitat for 85 species of North American birds that either excavate holes, use natural cavities, or use holes created by other species (Scott et al. 1977). Additional bird species use the external portions of snags to meet habitat needs.

Mammals, reptiles, amphibians, and invertebrates also need snags. A limited review of Burt and Grossenheider (1964), Davis (1960), and supplemented by personal knowledge, indicate a minimum of 49 species of mammals that use natural and created cavities in snags. The dependency of these species on snag habitat may not be as well documented as that of cavity-dependent birds, but

this does not diminish the fact that snags are important to mammals.

Snags provide habitat for wildlife to meet basic behavioral and physiological needs. Such needs include but are not limited to:

Singing	Viewing	Hawking
Pecking	Seeking	Capturing
Drumming	Grooming	Perching
Excavating	Incubating	Brooding
Reproducing	Hibernating	Roosting
Hunting	Landing	Feeding
Loafing	Regulating	Gleaning
Nesting	Constructing	Estivating
Resting	Enticing	Plucking
Courting	Competing	Defending
Preening	Escaping	Rearing
Wedging	Communicating	Raking
Hiding	Observing	
Storing	Climbing	

Snag habitat and cavity nesters are as necessary to the Forest as the trees.

Some people believe that a forest can exist without these components, but I am not one. Little do they understand the intricacy of the system, and those that cannot understand will eventually eliminate these components and the forest.

REFLECTIONS OF PROGRESS

In preparation for this symposium, it was only natural for me to reflect upon the progress that has been made in the past 10 years. In these reflections, I could not help but have mixed feelings.

When I transferred to the West in 1972, I, like maybe some of you, had not really given much thought to the value of snags as wildlife habitat. Yes, I had grown up observing standing dead trees in the forest. They were the trees that one could

¹Paper presented at the Snag Habitat Management Symposium [Flagstaff, Arizona, June 7-9, 1983].

²Jerry W. Davis is the Forest Wildlife Biologist, USDA Forest Service, Tonto National Forest, Phoenix, Arizona 85038

tap and watch owls, bats, rats, woodpeckers, bluebirds, and flying squirrels come out of the holes. On occasion, unexpected occupants including lizards, bees, wasps, and mosquitoes, would emerge. Many of the squirrels that the dog treed were in hollows, and the old trees with the hole at the base seemed to be where the rabbit would take cover when chased by a dog.

Dead trees were present and were considered part of the forest. When they fell, the logs were also accepted. Logs were turned over by curious boys to find rodents, snakes, lizards, and invertebrates. Logs produced "wood sawyers" and other insect forms that were used to catch the fish laying under the logs in the river.

All of these stages - the dead tree, log, and large woody debris - were accepted as an important and functional part of the system to which they contributed.

In 1972, I was surprised to find that snags and logs were not being accepted as part of the forest, although data indicated over sixty species of wildlife on the Kaibab National Forest used snag habitat. There was, and had been for many years, a conscious effort to remove snags from the system. Timber sale contracts required the purchaser to fell a specified number of snags, and he was given purchaser credit to do so. Salvage sales scheduled between timber sales insured that fewer trees "went to waste." Fire management called snags "lightning rods" and perceived them as standing beacons to attract fire. Other professional disciplines viewed the presence of snags as a disgrace and a waste.

It was during the early 1970's that a forester proudly announced that the last snag had been removed from one of the National Forests in Arizona. Decades of snag removal had been effective on accessible areas of other Forests as well.

In July 1973, snag management began to improve with the approval of a Regional Snag Management Supplement (USDA 1973). It required that a snag determine its own value by retaining those being used by wildlife. In addition to snag protection in timber sales, it requested Forest Supervisors to issue manual supplements protecting them from woodcutters.

Forest snag management supplements did follow in time. In July 1974, the Kaibab National Forest had an approved supplement which provided snag retention except in clear cuts, fuelbreaks, recreation areas, travel influence zones, and hazardous snags which by virtue of their position posed a hazard to fire protection. Timber markers were required to designate with paint those snags to be removed rather than mark the snags to be retained (USDA 1974).

Some may not see this as progress, especially with all of the exceptions, but in the early days

of snag habitat recognition, it was progress. It was also progress to later reduce salvage sales, protect snags in timber sale contracts, and reduce the size of fuelbreaks from 48 percent of the total area for some sales, to 8 percent or less. Management data and improved awareness and attitudes seemed slow in happening. But they did happen and so did the improvement of Regional and Forest snag management policies.

The evolution of data were also necessary. It was not enough for a wildlife biologist to identify the problem and request snag habitat. Published data were needed to support answers to even the most basic questions of how many and what kind of snags should be retained.

Balda (1975) and Scott (1978) provided some of the answers. Balda, working with secondary cavity nesters in natural ponderosa pine forests, supported maintaining 268 snags per 100 acres. Scott's research supported 2.5 snags per acre as the lower rather than the upper limit. Scott also supported retaining snags greater than 15 inches dbh, taller than 75 feet, and greater than 40 percent bark cover.

Cunningham, Balda, and Gaud (1980) revised Balda's 1975 data to support densities of 5.2 snags per hectare, emphasized the importance of bark, and determined a relationship between the number of nest sites to snag density. The value of snags as winter roosts and the importance of size and height were also determined.

Since the mid-1970's there have been numerous papers providing data on snag habitat and cavity dependent species. Most of these papers have been published in the past few years. Classification terminology, including hard and soft snags, and primary and secondary cavity nesters, were once seldom heard. Today they are commonly used and recognized.

It is exciting to be a part of the first snag management symposium. Letters and telephone calls of support have been received from throughout this nation, Canada, and Australia. The Reston Home Owners' Association sent a copy of the guidelines that are used to manage 1,000 acres of open space to protect snags and encourage cavity users.³ A letter received from the Connecticut Department of Environmental Protection expressed their personnels' inability to attend the symposium but enclosed a copy of the State's guidelines for snag management. These guidelines included criteria for snag selection, size, distribution, management density (3-7 snags per acre), and future snag production.⁴

³Thompson, Claudia. 1983. Personal correspondence. Reston Home Owners' Association. Reston, VA.

⁴Lutz, Karl J. 1983. Personal correspondence. State of Connecticut Dept. of Environmental Protection. Marlborough, CT.

Exciting things are happening in snag habitat management and progress has been made. Many people seem to be extending their ideas beyond the utilitarian philosophy. They are saying that wildlife and other elements of the ecosystem have an important purpose whether we have justified their existence economically or not. Society is expressing discontent with the management of our forests as wholesale warehouses for commodity shoppers, and support the right of existence for wildlife and plant species.

With so many positive things happening, it is easy to become dazzled by our own fancy footwork and assume that the problem is solved. Progress has been and continues to be made, but we are not there yet.

PROBLEM RECOGNITION

The first step to solving a problem is to realize that a problem exists. Problem recognition is not always easy and may be blurred by personal values, underlying philosophies, insensitivity, and limited knowledge.

When I was growing up in East Texas, my father had a farm adjoining Davy Crocket National Forest. One day when we were working, he pointed out a red-headed woodpecker (Melanerpes erythrocephalus) constructing a nest cavity in a Texas Power and Light Company utility pole. "That woodpecker is my fence builder," he said. "Woodpeckers need a place to nest and since there are not many dead trees anymore, they build their nests in utility poles. When the company replaces the poles, I buy the damaged poles for fence posts."

Today, woodpeckers are still using utility poles. Continental Telephone of Texas reports that 12.5 percent (204) of the poles replaced in 1981 was because of woodpecker damage.⁵

Texas Power and Light Company reports that in the past four years, pole damage has been due to decay below ground, damage by vehicles, lightning strikes, and woodpecker damage, in that order. L.S. Huntsinger, Division Superintendent, said "We do have many poles that sustain woodpecker damage that are not replaced. In our transmission lines which are generally taller we have a large percent of woodpecker damage; however, this has been offset to a great degree because we now wrap one-quarter inch wire mesh around these poles."⁶

In the 1950's there were reports of a decline in wood duck (Aix sponsa) and Eastern bluebird (Sialia sialis) populations. A milk company tried to improve the nest habitat for bluebirds by pro-

ducing milk cartons with instructions on how to convert them into nest boxes. Many people responded and there seemed to be a temporary increase in bluebirds.

I spent hours fishing on lakes constructed by the Corps of Engineers and was amused watching cavity nesters using the few snags standing above the water surface. Little did I think at the time that these few snags were token remnants of a forest that would never provide a self-sustained supply of snags again.

These and other examples illustrate symptoms of the problem. The problem is a rapidly declining habitat for snag and cavity dependent species. This problem has many symptoms and many causes which are not unique to this nation, but are worldwide. It is a problem that can be recognized, whether it be by the use of nest boxes in the intensively managed forests of Europe or by the rapidly disappearing forests of countries that are mining timber resources to meet world trade and balance of payment demands. Symptoms of this problem can even be observed at your local zoo by noting the cavity nesting species that are in trouble all over the world.

There are many causes contributing to the problem. One has only to think about the diverse influences altering the composition, density, and existence of our forests. Causes can be as obvious as extensive type conversions for the development of agricultural lands, for urban expansion, or establishing short rotation monoculture tree farms. They can be as subtle as the change in forest age classes, species composition, and rotation, or as quiet as the almost indiscernable grazing of livestock on cottonwood and sycamore regeneration.

Although most causes of the problem are obvious, some may still fail to be recognized because of a limited knowledge. Some people, however, do not recognize the problem and its causes because for one reason or another they choose to believe that everything is still OK. They could be compared to a man jumping off of Hermit's Rest at the rim of the Grand Canyon to the Colorado River a mile below. As he falls, he can be heard saying as he passes each 500 foot mark "everything is still OK, everything is still OK...". It is that sudden realization at the end of the line that is going to have the impact and then it will be too late.

Everything is not OK and the sooner we realize that a problem exists and start working toward resolving the causes of the problem, the better off all resources, and non-resources, will be.

Some of the causes of the problem are unique to localized areas, whereas others, such as fuelwood demand, both legal and illegal, and timber management practices, have a common thread nationwide.

⁵Fryer, Jim. 1982. Personal correspondence. Continental Telephone of Dallas. Dallas, TX.

⁶Huntsinger, L.S. 1982. Personal correspondence. Texas Power and Light Company, Tyler, TX.

Fuelwood demands have developed at a significant rate since the 1974 oil embargo. It is possible that much of the fuelwood problem was self-inflicted due to improper planning, inadequate funding, and an eagerness to advertise free fuelwood to encourage everyone to save fossil fuels. During this period of energy crisis, to burn fuelwood was not only patriotic but was supported by economic motivation.

Americans responded by installing fireplaces and woodburning stoves. These not only were thought to be essential to save energy but became a status symbol as well. This cultivated the Paul Bunyan syndrome. Forest dead and down fuelwood was not enough; the budding Paul Bunyans had to cut and watch their own trees fall. Forests and private landowners who had just a few years before paid to have trees pushed, piled, and burned were now faced with a limited supply.

Demand continues to increase and so does the fuelwood support industry. Baker (1983) reports that this nation burns over 40 million cords of wood per year to meet about one percent of our energy needs. He estimates that this will triple in the next decade.

Forty million cords of wood represent a stack of wood 4x8 feet, 30,303 miles high. If this use triples as projected it will take this nation less than three years to use a stack of fuelwood 4x8 feet extending from the earth to the moon.

Fuelwood use has been re-ingrained in the American lifestyle and continues even if it is not economical. Fuelwood users in the Phoenix area may pay \$100-\$140 per cord. In an improved fireplace, they will only receive \$20 of natural gas BTU equivalents.⁷

Fuelwood demands are real, and so are the adverse impacts that rampant illegal cutting is incurring on the management efforts to replace and maintain snag habitat.

The management of forested lands with emphasis on the production of commodity products also adds to the problem of snag habitat management. Increasing demands are being made to produce more wood products from a renewable yet finite timber resource.

It is the same land and forest base that must provide wildlife habitat for indigenous species. Yet, the inadequacy of parity between commodity and noncommodity outputs pose questions that need answers.

I see intensified timber management and harvest through shorter rotations, even-aged management, fire suppression and fuels control, optimum spacing, frequent re-entries, and aggressive insect

and disease control. I watch the final removal of mature timber from the last stands. Even areas that were once inaccessible and uneconomical to harvest and were said to be left for wildlife are now being harvested.

With more intensive management, shorter rotations, and healthier forests, I question if we are prepared mentally, and will support financially and with research data, efforts to create adequate snag habitat. Under these conditions, it may be unrealistic to expect adequate snag habitat through natural mortality.

Timber management policy and practices have the greatest potential to contribute to or resolve the causes to the problem of inadequate snag habitat.

PROBLEM RECOGNITION - NOW WHAT?

I do not have great words of wisdom that I can give you to solve the problem. I believe, however, that by recognizing the problem and surfacing causes and concerns, that the solutions can be implemented. It cannot be solved by wildlife biologists alone, but it will take a multifaceted, multidiscipline approach looking at the problem from the various viewpoints.

I am hopeful that the papers and data presented at this symposium will be a turning point in solving the problem. It should provide an opportunity to exchange information and ideas, and the published proceedings will provide a reference to professionals of all disciplines. We cannot, however, be content with these efforts and brief exchanges.

After this symposium, we do not need to continue talking to ourselves. We are not the ones that need to be convinced that snag habitat and its dependent species are of value and are worth saving. If there is one person in this nation that is not aware of the values of snag habitat, that is one too many.

There must be an improvement in attitudes, awareness, and sensitivity. We need to reassess our management purpose and revive our land ethic. I do not feel that the true intent of multiple use can be met unless all are willing to adjust the way that it has been applied. The reason that snag habitat is in trouble is that its value has not been generally perceived although the value is there. All need to be advocates for total resource management.

Researchers must remember that decisions are being made everyday, whether data and answers are available or not. This obligation goes beyond getting data in print. You are in the position and have the background to be most sensitive to resource needs, provide data, and help integrate the multiple needs and demands that are made on finite resources.

⁷Davis, Jerry W. 1980. Unpublished Paper. Fuelwood Cents. Phoenix, AZ.

Researchers and managers alike must be careful not to get trapped on the data carrousel or use the lack of data as an excuse for inaction. Data alone will not solve the problem. We must be careful not to be a society with volumes of data in print and lose the resource because the solutions were never implemented.

Resource managers should support the concept that this habitat and its species are not just for the wildlife biologists but are everyone's resource and management responsibility. Wildlife biologists do not need snag habitat anymore than the manager, forester, recreationist, educator, or commodity interest. Snag habitat should be managed as intensively and with as much enthusiasm, dedication, and commitment as other resources. Concern should be as great for the illegal removal of snags as it is or would be for the illegal removal of commodity species.

The managers of public lands and industry alike should reassess the abilities of these lands to produce commodity products with equal consideration for other resource needs. We must face on-the-ground production realism vs. unrealistic production figures.

Every discipline must realize that it is our obligation to relinquish the land resources to future generations, with nothing less than its inherent potential to produce, and not in a diminished, but in an enhanced, condition. To do anything less than this means that we have been a failure in managing the resource and meeting the intent of our purpose.

John McGuire (1982), past Chief of the Forest Service, said that the National Forest System began as an experiment in public land ownership with the aim to insure a nondeclining, even flow, decade by decade, forest by forest, in perpetuity. This policy, he said, was not specifically written into the law, but was an agency interpretation. This interpretation was controversial, so Congress adopted as law the even flow interpretation of sustained-yield policy.

To manage resources on an even flow, sustained yield, in perpetuity means that we should manage them on a non-declining basis through eternity. Snag habitat and its associated wildlife species are such resources.

I am proud of the leadership that the Forest Service has taken in the past to recognize the special habitat values of riparian habitat, the management of nongame birds, and the cosponsorship of this symposium. I think that it would be appropriate to have another symposium in the Fall of 1985 to pull together data on the management of wildlife species requiring special habitat components. The symposium should include data on snags, hollow trees, cavities, logs, forest litter, and woody debris as they relate to the terrestrial and aquatic systems.

CONCLUSION

Snags provide essential habitat for wildlife, and their value to the forest system is irrefutable. We have made progress in the past decade, but the problem of inadequate snag habitat persists. If we are going to solve the problem, everyone must realize that a problem exists and be willing to implement solutions. Professionals from all disciplines must maintain an acute sense of resource awareness and urgency. We must remember that published data alone will not solve the problem.

As we work toward problem solutions, we should keep in mind the works and resource ethics of a forester who walked the forests of the Southwest six decades ago. Aldo Leopold (1966) said, "A system of conservation based solely on economic self-interest is hopelessly lopsided. It tends to ignore, and thus eventually to eliminate, many elements in the land community that lack commercial value, but that are (as far as we know) essential to its healthy functioning. It assumes, falsely, I think, that the economic parts of the biotic clock will function without the uneconomic parts."

Leopold also said: "The outstanding scientific discovery of the Twentieth Century is not television, or radio, but rather the complexity of the land organism. Only those who know the most about it can appreciate how little is known about it. The last word in ignorance is the man who says of an animal or plant: What good is it? If the land mechanism as a whole is good, then every part is good, whether we understand it or not. If the biota, in the course of aeons, has built something we like but do not understand, then who but a fool would discard seemingly useless parts? To keep every cog and wheel is the first precaution of intelligent tinkering."

That is our job as resource managers and professionals. It involves saving all of the pieces in adequate quantities to maintain an efficient and viable ecosystem on a sustained-yield for the present and for the future.

Snag habitat and its associated wildlife are important pieces that we must retain.

Snags are for wildlife.

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The Role of Nestboxes in Bird Research and Management¹

Jeffrey B. Froke²

Abstract.-- Modern management of cavity-nesting birds has evolved from over 240 years of nestbox use by humans. Species have been maintained using nestboxes for economic, aesthetic, scientific, and conservation purposes. Implications of nestbox studies for management, including several risks of using nestbox derived data, are discussed.

INTRODUCTION

Progress in the scientific study and management of cavity-nesting birds in this century is largely due to the creative and extensive use of nestboxes. Detailed information on breeding biology and population dynamics of several species (e.g., the Great Tit *Parus major*, Pied Flycatcher *Ficedula hypoleuca*, and Eastern Bluebird *Sialia sialis*) is available because of their readiness to nest in boxes. At least 102 bird species are represented in nearly 1,000 nestbox-oriented studies in the international literature.

This paper presents historical background, and discusses implications of nestbox studies for wildlife management in artificial and natural cavity habitats. Properly used, nestbox-derived data are potentially useful to the design of snag management prescriptions by wildlife biologists and foresters.

HISTORICAL BACKGROUND

Pre-20th Century

Carolus Linneaus (in Phillips 1925) reported that Scandinavians over 240 years ago hung nestboxes in trees for Common Goldeneyes (*Bucephala clangula*) to provide a harvestable supply of eggs for human consumption.

In North America, the Purple Martin (*Progne subis*) benefited from the hospitality of Indians and white settlers, and they from the presence of the martins. Alexander Wilson (1831) wrote: "even the solitary Indian seems to have a particular respect for this bird. The Chactaws and Chickasaws cut off all the top branches from a sapling near

their cabins, leaving the prongs a foot or two in length, on each of which they hang a gourd, or calabash, properly hollowed out for their convenience." John James Audubon (1831) observed the relationship between the Indians and martins, and explained: "the bird keeps watch and sallies forth to drive off the Vulture that might otherwise commit depredations on the deer-skins or pieces of venison exposed to the air to be dried." Mark Catesby (1731) noted that the settlers of Florida and the Carolinas had adopted the Indian's accommodations to martins: "they breed like Pigeons in Lockers prepared for them against Houses, and in Gourds hung on Poles for them to build in, they being of great Use about Houses and Yards for pursuing and chasing away Crows, Hawks, and other Vermin from the Poultry."

Audubon (1831), in his dedicated scientific travels, noted that: "Almost every country tavern has a martin box in the upper part of its sign-board."

20th Century

Economic values of martins, bluebirds, and other insectivorous cavity-nesting species have continued to justify their management using nestboxes to the present day. W.L. McAtee (e.g., 1940) with the Bureau of Biological Survey, performed extensive experiments using nestboxes to increase numbers of birds for control of nut weevils and other injurious insects in orchards. Since McAtee's work, there have been numerous major research programs dedicated to increasing insectivorous bird populations in timber and food crop environments; and Russian ornithologists (see Poznanin 1956) particularly have used large number of nestboxes for this purpose.

At the 1930 meeting of the International Committee for Bird Preservation, chaired by National Audubon Society president T. Gilbert Pearson, Sokolowski (1931) described Poland's new national nestbox program aimed at replacing disappearing old-growth forests suitable for cavity-nesting birds. Following an epidemic of noctuid caterpillars which deforested much of Poland, boxes designed by Sokolowski and suitable to 16 species were widely used

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²Jeffrey B. Froke is Sanctuary Manager, National Audubon Society, Trabuco Canyon, Calif.

by private citizens and the government in every national forest. Manufacture of tens of thousands of nestboxes was the job of prison workshops, schools and other state institutions. Massive nestbox projects for forest and orchard insect control continue today to characterize Polish ornithology (e.g., Graczyk 1974, Graczyk et al. 1970).

In 1930, Musselman (1934, 1940) was concerned about the effects of habitat loss on Eastern Bluebirds in Illinois, and noted that the old-time fences, wood fence posts, and stubs of apple trees which formerly had hosted the excavations of Downy Woodpeckers (*Picoides pubescens*) and, by inheritance, the nests of bluebirds, had disappeared. The fences had been replaced by iron and wire, while modern horticulture dictated that orchard trees be trimmed and stubs be painted. Musselman promoted the use of nestboxes to fill the nest site deficiency and to stem the decline of bluebirds. The now popular and effective institution of nestbox projects including multi-state and -province "trails", hundreds of miles long with thousands of monitored and maintained boxes is accredited to Musselman; and the subject has been carefully reviewed by Kibler (1969).

Frank Bellrose (1976), who has been a luminary in American waterfowl management, reminded us that in the early 20th century, the Wood Duck (*Aix sponsa*) was feared to follow the Laborador Duck (*Camptorhynchus laboradorius*) into extinction. Overhunting caused the decline before rigid enforcement of new protective laws permitted its dramatic increase into the 1940's. It was apparent to waterfowl managers, however, that suitable nest sites were in short supply, and that a saturation of available breeding habitat was close at hand. Consequently, in 1939, personnel of the Illinois Natural History Survey erected several hundred boxes for the ducks, and witnessed a 52% occupancy in the first season. Bellrose (1976) emphasized the drastic impacts of bottomland drainage and timber harvest on Wood Duck populations, and left the question of determining to what extent there is a "trade-off" between an increase of duckling production from nestboxes, and a population decline due to loss of natural habitat.

Incidentally, Hesselschwerdt (1941) prepared an economic analysis of the Illinois duck box project, and summarized that in addition to ducks, 56 boxes constructed at a cost of \$98 and placed in a 4 square-mile farmland, during the first 2 years produced a total of 32 young Screech Owls (*Otus asio*), 19 young American Kestrels (*Falco sparverius*), 37 young Fox Squirrels (*Sciurus niger*), 112 pounds of honey, and good winter shelter for a number of wildlife species.

Concurrent early waterfowl programs in Scandinavia included the nestbox work of Siren (e.g., 1951) on Common Goldeneyes in Finnish lakes, and Grenquist (e.g., 1953) on Gooseanders (*Mergus merganser*) on the Finnish archipelago. In similar spirits as Purple Martins which nested in empty jugs provided by early American settlers, Finnish Gooseanders benefited from the secondary values of old packing cases for whiskey and brandy that had washed ashore from passing vessels. Later, these

cases were brought directly from Helsinki by Grenquist and colleagues.

Since the early scientific observations by Wolda (1917) and others that populations of certain passerines could be increased and controlled by use of nestboxes, there has evolved an abundance of detailed long-term studies on the Great Tit (see Perrins 1980), Pied Flycatcher (see von Haartman 1971), and other Eurasian species. The Wytham Woods program of the Edward Grey Institute near Oxford, and the "hole-breeders programme" of the Vögelwelt Helgoland in Germany are particularly notable for extensive field investigation of cavity-nesting birds using nestboxes and banding.

IMPLICATIONS FOR MANAGEMENT

Although there are clear advantages of nestboxes as research tools (i.e., accessibility of nests, eggs, and birds; experimental control, etc.), there are risks involved in relying on boxes as primary sources of breeding data. Van Balen et al. (1982) reviewed and presented new data on the problems of nestbox populations deviating from populations occupying natural nest sites in: 1) breeding density, 2) composition of breeding species, 3) clutch size, and 4) nesting success. The authors argued that, with the exception of their present study and that of Nilsson (1975), too few systematic studies of cavity-nesting birds in natural cavities are available to give relevance to box-derived data.

Population Trends

In their 30-year study of Screech Owls in Ohio, VanCamp and Henny (1975) stated that boxes may affect bias in data, particularly in terms of population trends and rate of annual recruitment. They warn that trends in regional populations should not be based on percent of box-occupancy each year, because boxes are often placed in optimal habitat, and population changes caused by alteration of suitable natural habitat would be underestimated by this approach. Box and cavity data should be segregated for population estimates.

Nestbox Preference

Preference by birds for nestboxes over natural cavities apparently is common in several species. Ben Pinkowski (1976) reported 72% selection of boxes by pairs of Eastern Bluebirds in an area where natural cavities were available; and he suggested that boxes may have been selected because they were in more suitable locations and had more optimal interior dimensions.

In order to evaluate the cost-effectiveness of a Mississippi Wood Duck nestbox project which had a box utilization rate of more than 90%, Strange et al. (1971) investigated the availability and possible duck use of local natural cavities; and found that, although tree cavities were available, none was used due to an apparent preference for nestboxes.

Relative nesting success in nestboxes versus natural cavities is a major consideration for management which aims to sustain populations by natural reproduction. As part of a 12-year study of Black-bellied Whistling Ducks (*Dendrocygna autumnalis*), Bolen (1967) found predation to be a major factor of nest failure in boxes and natural sites: natural cavities and boxes without predator guards had 44% and 46% nest success, respectively; and boxes with guards had 77% nest success. Similar data of Bellrose et al. (1964) for Wood Ducks included 40-49% in natural cavities, 36% in unprotected boxes, and 73% success in boxes with predator guards.

Accepting Kalmbach's (1939) conclusion that 70% minimum nest success is required for satisfactory waterfowl management, these data for Wood Ducks and whistling ducks indicate the futility of erecting unprotected nestboxes or relying on non-modified tree cavities for duckling production.

L.F. VanCamp and C.J. Henny (1975) contended that due to a reduction of European Starlings (*Sturnus vulgaris*) in boxes within the feeding area of Screech Owls, Wood Duck nesting success is enhanced by presence of nesting owls and resultant reduced starling competition; and, therefore, management should provide adequate numbers of nest sites for both owl and duck species.

The benefit of nestboxes to increase nesting success by reducing interspecific competition for nest sites is highlighted by the Puerto Rican Parrot (*Amazona vittata*) recovery program (Wiley 1980, Snyder and Taapken 1981). Competition with the parrots for nest cavities by the Pearly-eyed Thrasher (*Margarops fuscatus*) has been a serious limiting factor against population recovery by the parrot. Placement of optimally configured thrasher nestboxes near parrot boxes has diverted thrashers from the parrot nests; and the territorial thrashers protect the nest vicinity of both species by fending off intruding other pairs of thrashers.

Blowflies (Diptera: Calliphoridae) are common ectoparasites of cavity-nesting birds, and may limit nesting success by weakening or killing nestlings (Kenaga 1961). In Eastern Bluebirds in the Huron National Forest, Pinkowski (1977) found that blowflies (*Apaulina* sp.) parasitized natural cavities and nestboxes at comparable rates (85% and 82%, respectively). The difference in the mean number of parasites per loaded nest, however, was significant, with 51.5 in natural cavities, and 91.4 in nestboxes. The author explained that blowfly numbers are affected by the amount of grass nesting material available as blowfly habitat, and the larger size and square shape of boxes require the bluebird to add more grass to make a nest cup, thereby increasing the number of parasites in the nestbox. Therefore, box designs that conform to dimensions and shapes of natural cavities would be beneficial to bluebirds, as would management for more natural cavities available to the species.

Nestboxes provide amateur and professional ornithologists and conservationists with a convenient and essential tool for their work to understand and maintain populations of cavity-nesting birds. Direct and controllable access to the contents of a nest cavity, or to the contents of many nest cavities, permits evaluation of the success of both the nesting birds and our management effort. Flexibility of the design and placement of nest sites provides for limitless experimentation, and hence a greater insight to the relationships of the nesting bird and its physical and biological environment.

Nestboxes obviously do not replace natural cavities; and they cannot effectively mitigate for the loss of natural nest sites in avian habitat. The majority of box-oriented studies relates to specific geographical and ecological conditions surrounding a limited number of species; and replication of multiple-species communities using nestboxes in the absence of natural habitat is not possible. Nestbox programs of the large extent common in Europe and occasional in North America are, when properly monitored and maintained, expensive. Wildlife and forest managers require detailed biological and economic information for cost:benefit analysis decisions to integrate possible nestboxes into forest management programs for cavity-nesting birds.

If nestboxes are to be considered in a management program, it is recommended that planners take full advantage of the extensive and intensive literature and experience on the subject, a minor portion of which has been introduced in this paper.

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Power Pole Damage by Acorn Woodpeckers in Southeastern Arizona¹

G. Patrick O'Brien²

Abstract. Southeastern Arizona utility companies experience extensive damage to power poles by acorn woodpeckers (*Melanerpes formicivorus*). Woodpecker cavities existed in 54 percent of 266 power poles inspected and resulted in an average of 1.5 cavities per pole. The mean depth of 49 cavities was 31.8 cm and ranged from 15.2 cm to 54.6 cm. A single power pole was found to contain 5 cavities which resulted in a combined cavity depth of 168.3 cm.

INTRODUCTION

The acorn woodpecker (*Melanerpes formicivorus*) inhabits oak and oak-pine woodlands in Oregon, California, Arizona, New Mexico and southward into Columbia (Dawson 1923, Ridgway 1914, Skutch 1969). In Arizona the species is a resident of oak and oak-pine belts throughout the state, with the exception of extreme northern portions (Phillips, Marshall and Monson 1964). Bock and Bock (1974) reported that populations in Arizona, New Mexico and Texas are considerably fewer than in Pacific regions due to a lack of oak species diversity. Acorn woodpeckers are socially communal during all periods of the year and exist in groups of 2-10 (Bent 1939, Dawson et al. 1923, Stacey 1979). All members of a group contribute to territorial and food defense, cavity construction and the care and feeding of young (McRoberts 1970).

Acorn woodpeckers are widely known for their unique habit of storing acorns in the cracks and crevices of trees, posts, and poles (Bailey 1928, Bent et al. 1939, Phillips, Marshall and Monson et al. 1964, Ritter 1938). The woodpecker creates small holes in trees, posts and poles where they force acorns for storage and such storage areas will often cover an entire branch or pole. Dawson (et al. 1923) observed a pine tree in California estimated to contain 50,000 imbedded acorns. Acorn storage areas in southeastern Arizona were found on the dead branches of walnuts, sycamores, cottonwoods, junipers and on power poles. Major foraging methods in Central America includes

gleaning, flycatching, sap feeding, acorn storage and probing (Stacey et al. 1979). Acorn woodpeckers are expert flycatchers and display amazing aerial acrobatics when pursuing winged insects. McRoberts (et al. 1970) reported the collection and storage of insects as being common during the nesting period. A woodpecker was observed to catch a flying insect, whereby it took it to a nearby power pole and immediately placed it in a narrow crevice. The insect was removed and relocated twice more before being left. Apparent sap holes have been observed in the trunks and branches of oak trees, although direct use of these sites was never noted. Even though acorn woodpeckers are known to consume ants, the importance of the insect and application of the name formicivorous (ant eating) is considered inappropriate, since ants constitute only an occasional portion of the diet (Dawson et al. 1923).

Nesting and roosting cavities of acorn woodpeckers are reported to exist in oaks, sycamores, pines, eucalyptus and power poles (Bailey et al. 1928, Dawson et al. 1923, Rumsey 1973, Skutch et al. 1969). Woodpecker cavities in the study area were observed in the branches and trunks of walnut, ash, cottonwood, juniper, willow, oak, sycamore and pine, as well as power poles.

Brant (1951) reported that of the 7 breeding woodpeckers in southeastern Arizona, the acorn woodpecker was the latest nester (peak in June). It appears that an undetermined segment of the population vacates southeastern Arizona during late winter and does not return until near the breeding season, although some groups remain throughout the year. The availability of vacant acorn woodpecker cavities allows for many earlier cavity nesting birds to use the sites. Suspected or observed nesters inhabiting acorn woodpecker cavities includes the elf owl (*Micrathene whitneyi*), flicker (*Colaptes cafer*), bluebird (*Sialia sp.*), kestrel (*Falco sparverius*) and coppery-tailed trogon (*Trogon elegans*). Of these species, only the trogon would possibly conflict

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²G. Patrick O'Brien is a Wildlife Manager with the Arizona Game and Fish Department, Sierra Vista, Arizona.

with the nesting period of the acorn woodpecker.

Woodpecker damage to power poles is known to occur throughout the southern, southwestern, southeastern and northeastern portions of the United States and into Central America (Rumsey et al. 1973, Skutch et al. 1969). Rumsey (et al. 1973) listed pole damaging species to include the pileated (*Hylatomus pileatus*), red-headed (*Melanerpes erythrocephalus*), ladder-backed (*Dendrocopos scalaris*) and golden-fronted (*Centurus aurifrons*) woodpeckers. The acorn woodpecker must certainly be added to this list and it is also possible that other species either contribute to or receive blame for pole damage. For instance, it is common to observe flickers on damaged power poles, although I have never observed them pecking on them.

Utility companies experiencing woodpecker damaged poles have tried a variety of methods in alleviating the problem. Such efforts have involved the shooting of offenders, the use of fiberglass and cement poles, protective plastic and wire meshing, offensive chemicals and simulated snakes attached to poles (Benton 1966). Where severely damaged poles have been replaced, the damaged pole has often been left in an effort to eliminate damage to the new pole.

The southeastern Arizona based Sulphur Springs Valley Electric Power Cooperative has long expressed a concern with woodpecker damage to power poles and concedes that their damage is undoubtedly less than other areas. Even though damage by ladder-backed woodpeckers is known to exist in the area, the major problem involves the acorn woodpecker. From 1978 to 1982 the power cooperative replaced 74 utility poles specifically related to woodpecker damage. Numerous other pole replacements involving woodpecker damage occurred during this period, but were not replaced specifically for that purpose. Damage involved numerous partial holes, riddled cross-arms, deeply penetrated pole tops and cavities. Even though the 74 woodpecker damaged pole replacements represented less than 1 percent of about 10,000 poles examined during the period, severely damaged poles were unusually concentrated in localized problem areas. For example, 3 individual poles were replaced a combined total of 7 times during the 5 year period and even when the damaged pole was left standing, woodpecker damage continued to occur on the new poles.

Power pole replacement in itself is expensive and is compounded by the fact that woodpecker damage severely reduces pole longevity. Increased expenditures for pole purchases, labor, materials, gasoline, paperwork and accounting due to such damage is certainly reason for concern. A typical example of replacement costs due to woodpeckers is illustrated by the following case in-point. The Sulphur Springs Valley Cooperative received a call from a service member concerning woodpecker damage to a power pole near his residence. The area superintendent dispatched a service crew to inspect the complaint and they recommended immediate pole replacement due to woodpecker damage. The following day a small line crew and hot-line crew drove

1 hour to the site and spent 4 hours replacing the pole without interrupting power to customers. The total cost for replacement of the single pole was \$1294.12. If this figure is multiplied by the 74 poles replaced to woodpecker damage over the 5 year period, the added cost to consumers was \$95,764.88.

STUDY AREA - METHODS

The study area was confined to portions of Cochise and Santa Cruz Counties in extreme southeastern Arizona. Major tree species included Emory oaks (*Quercus emoryi*) and alligator juniper (*Juniperus deppeana*), with lesser amounts of white oak (*Q. arizonica*), Mexican blue oak (*Q. oblongifolia*), netleaf oak (*Q. reticulata*), silverleak oak (*Q. hypoleucoides*), Toumey oak (*Q. Toumeyi*) and Palmer oak (*Q. chrysolepis*). Drainages contained walnut (*Juglans major*), Ash (*Fraxinus velutina*), cottonwood (*Populus fremontii*), willow (*Salix* sp.), sycamore (*Platanus wrightii*) and Chihuahua pine (*Pinus leiophylla*).

Seven survey routes involving 30.6 km were conducted in the study area. The shortest route was 0.4 km and the longest was 9.4 km. Pole inspection involved driving the survey route where woodpecker cavities, exposure, height, line direction, and observed acorn woodpeckers were recorded. The number of cavities observed were considered a minimum since only 3 sides of a pole were usually observed. Tree cavities observed in the study area were recorded for a comparison of use and availability. A limited number of tree and pole cavities were measured with reference to entrance width and cavity depth. Power pole measurements involved the use of utility company linemen.

FINDINGS

Two hundred and sixty-six power poles were inspected along 30.6 km of survey route and involved 144 (54%) woodpecker damaged poles (Table I). The greatest intensity (85%) of cavity poles on an individual route involved 69 of 81 poles. The total number of cavities observed on cavity poles was 211 and averaged 1.5 per pole. Cavities per pole on individual routes varied from 1.0 to 2.1 and the total number of acorn woodpeckers observed during surveys was 73 (mean 3.8/km).

Table I. Woodpecker damage observed along survey routes.

Survey distance (km)	30.6
No. poles inspected	266
No. cavities observed	211
No. cavity poles	144
Cavities/pole	1.5
No. acorn woodpeckers	73
Woodpeckers/km	3.8

Acorn woodpeckers were observed perched on most points of power poles including the top,

sides, cross-arms, and occasionally wires. Wire perching was very uncommon and was observed only 2-3 times. Other than wires, no perching was ever observed on attached equipment such as transformers, bolts and insulators. Pole top and cross-arm perching occurred mostly during aerial feeding and food ingestion. Vertical pole perching was the most common overall activity and usually involved the upper one-third of the pole. During hot summer months, woodpeckers would often rotate on the pole so as to remain in the shade.

A slightly greater number of woodpecker cavities were observed to exist below the point of attached wires or cross-arms (Table II). Since attached wires and cross-arms are usually near the top of poles, a greater area for cavity construction lies below this point. Pole cavities varied from the extreme top to as low as 5 feet above the ground. In general, most cavity construction existed above the pole mid-point.

Woodpecker cavity entrances on poles were aligned with attached wires during 75 percent of all observations (Table II). Some bias undoubtedly exist in this data since vehicular transects always ran parallel to wire direction and because of this, all exposures of in-line cavities were observable, while only one non-lined side was visible. Gila woodpecker (*Melanerpes uropygialis*) cavities in saguaro cactus revealed a mean (351°) orientation of near north, even though all exposures were used (Inouye, Huntly and Inouye 1981). Entrance exposures for cactus wrens (*Camphylorhynchus brunneicapillus*) are shown to change for radiation control during summer and winter months (Ricklefs & Hainsworth 1968) and woodpecker holes in Colorado aspen trees faced direction of maximum radiation (Inouye 1976). Data from Soule (1964) revealed that the summer temperatures within a cavity nest was influenced by the direction of orientation of the entrance. The outside shade temperature adjacent to a pole cavity at 1100 hours on June 6 was 90°F, while the temperature inside a north facing cavity was 86°F. At 1430 hours, the outside temperature had risen to 98°F and the cavity temperature to 93°F. This particular pole contained both north and south facing cavities which were used by woodpeckers. It is possible that multiple cavity exposures on an individual pole allows for thermoregulation during the varying seasons.

Table II. Power pole cavity entrance alignment

	Number	Percent
Above wire	108	46
Below wire	127	54
In-line	149	75
Non-lined	50	25
North	69	32
South	49	23
East	50	23
West	48	22

The extent of damage by woodpeckers to power poles is evidenced by the number and size of cavities, cross-arm damage and pole pecking. Forty-nine pole cavities were measured which contained a mean cavity entrance of 6.9 cm. and a mean vertical depth of 31.8 cm. Ten tree cavities in the study area were measured for comparison and were slightly smaller than pole cavities (Table II). The increased size of pole cavity entrance and depth indicates the ease of wood removal in soft pine poles. Cavity entrance measurements were slightly greater on the vertical than the horizontal, although it was not as exaggerated in tree cavities. A limited number of measurements of the width of pole cavities ranged from 11.4 cm to 16.5 cm. The pole diameter at one cavity was measured at 22.9 cm. while the cavity itself was 16.5 cm. Power pole strength is undoubtedly reduced where such large cavities occur. Many poles contained entrance holes that penetrated vertically for only a few centimeters (15-55 cm) and were not considered cavities suitable for woodpecker nesting. It was assumed that these holes were either in the development stage or were abandoned prior to completion. Such holes were commonly observed on both cavity and non-cavity poles.

Table III. Comparative measurements of pole and tree cavities.

	Sample	Entrance	Depth (cm)
Poles	49	6.9	31.8
Trees	10	5.6	28.2

Inasmuch as cavity poles in the study area averaged 1.5 cavities per pole, most poles contained multiple cavities. The greatest number of cavities found on a single pole was 5 and measured a combined vertical depth of 163.8 cm. Another pole, with an attached transformer, contained a single cavity with both north and south exposed entrances. The safety strength of this pole was greatly reduced since the cavity existed below the transformer. This was the only pole cavity found to possess double entrances. In addition to the aforementioned partial cavities, numerous entrance holes were observed which did not extend vertically and only penetrated the pole for about 8 cm. Numerous smaller holes were observed on both cavity and non-cavity poles and ranged in size from acorn storage size to larger. The majority of these were located on the upper one-quarter of the pole and were generally more numerous on cavity poles.

In an attempt to make some comparison of the use of trees and power poles by woodpeckers in the study area, 104 trees were observed to contain 192 cavities (1.9 cavities/tree). All tree cavities were found to exist in the dead branches of live trees or in dead trees. The only exception to this occurred in walnuts, where a limited number of cavities were found in live branches. Eight tree species were found to contain woodpecker cavities and the use of individual species was found to vary greatly (Table IV). Walnuts and pines comprised the greatest cavity use (53%) and

were followed by sycamore, cottonwood and oaks (39%). Juniper, ash and willow contained only 11 percent of the observed tree cavities. Walnut and pine trees were limited in the study area and were confined primarily to drainages, as were sycamores, cottonwoods, ash and willows. Oaks and junipers were widespread and abundant. Although cottonwoods were fourth on the list of tree species used by woodpeckers, cavities per tree was the greatest (2.8/tree) and is possibly explained by the fact that cottonwoods offered a greater number of dead branches. Chihuahua pines were abundant in an isolated area near the Cochise-Santa Cruz County line where telephone poles were also available. The incidence of pole damage in this area was minor considering the number of acorn woodpeckers inhabiting the area. A high incidence of use on dead Chihuahua pines occurred in this area. During the study the telephone line was being replaced underground and the poles removed. Upon removal of a pole known to contain an active woodpecker cavity, acorn woodpeckers were observed constructing a cavity in a previously uninhabited dead pine close by.

Table IV. Tree cavities observed in study area.

Species	#Trees	#Cavities	Cavities/Tree
Walnut	28	51	1.8
Pine	27	50	1.9
Sycamore	17	27	1.6
Cottonwood	12	34	2.8
Oak	11	17	1.5
Juniper	6	7	1.2
Ash	2	3	1.5
Willow	1	3	3.0
	104	192	1.9

CONCLUSIONS

Power pole damage by acorn woodpeckers is an expensive problem to utility companies in southeastern Arizona. Major damage exists in the form of cavity construction and cross-arm or pole pecking. Although the extent of damage varies by area, the expenses incurred by such damage is reason for concern. Utility companies have long sought answers to the problem and continue to seek methods of eliminating undue pole replacement, potential safety hazards, power outages and other inconveniences created by woodpecker damage.

Although the precise reasons for woodpecker use of power poles is unknown, several theories can be offered for explanation. It is most likely that the mere presence of soft pine poles in acorn woodpecker habitat offers them for use. However, other factors influencing the variance in intensity of use must be considered before seeking a solution to the problem.

Power lines throughout acorn woodpecker habitat in southeastern Arizona usually traverse riparian bottoms and oak woodland areas. It is felt that relatively pure stands of oak-juniper woodlands offer limited cavity sites for acorn woodpeckers when compared to riparian tree species or power poles. This is possibly due to the

hardness of oak and juniper woods and the limited availability of snags they offer. Riparian bottoms involving soft wood species such as walnut, sycamore and cottonwood are usually coincidental with the presence of power poles. That is to say that power lines traverse the habitat along wide bottoms and lightly wooded areas. Acorn woodpecker populations appear to be greatest in areas involving open woodland or riparian bottoms and in such areas the population may actually exceed the availability of natural tree cavity sites. Large dead branches of desired soft trees are continually breaking off or falling down and are no longer available for use. Power poles, on the other hand, are more stable and do not involve the undesired entanglement of numerous branches. The only exception to extensive power pole use in this study occurred in a single area where numerous dead pines were available for woodpecker use and power pole damage was light.

Since acorn woodpeckers show a preference for more open woodlands or bottoms, densely wooded areas contain limited populations. Transect number II of this study involved a wide riparian bottom with numerous sycamore, walnut and cottonwood trees. Adjacent hillsides contained light to moderate stands of oak and juniper. Of the 7 transect areas included in this study, it was estimated that this particular route (9.4 km) provided the best habitat for acorn woodpeckers. This was based on the availability of cavity trees and the number of woodpeckers observed per kilometer (4.7). Power pole damage on the other hand was the greatest of any route (85%). It may be that the woodpecker population actually overwhelmed the availability of natural cavity sites and therefore exerted increased use of power poles. However, it is not actually known whether native trees or power poles are the more preferred site and it may be that a combination of both enhances woodpecker populations. A removal of all power poles would probably affect woodpecker densities in most areas. There are sites where it is felt that power poles are the prime factor in influencing the density of acorn woodpeckers and without their presence, populations would be reduced.

In an effort to test alternate cavity sites along power lines, a 1.8 km route involving 14 poles was selected. Seven poles were found to contain a total of 15 cavities and involved approximately 8 resident acorn woodpeckers. Wooden boxes were designed to simulate cavities and were erected on cavity poles. Pole cavity entrances were blocked by placing a metal plate over the hole to eliminate use. Four of the 7 wooden boxes were observed to house acorn woodpeckers within 2 months of installation. However, woodpeckers retained a desire to use old cavities and created new entrances beside the plates on 4 occasions. One particular pole contained both north and south facing cavities which were simultaneously blocked from entry. Both cavities were eventually re-entered by woodpeckers below the plates and were blocked again. The south facing cavity was again re-entered and blocked for a third time. Acorn woodpeckers were observed using the box during the time of pole cavity re-entry.

The results of this limited study certainly lends credence to the fact that acorn woodpeckers inflict damage on power poles. Although the overall importance of power poles to population densities is uncertain, they are considered significant in many areas. The solution of how best to combat the problem inflicted on utility companies without adversely affecting woodpecker populations is yet to be determined. Cavity boxes may provide a partial solution, but it is doubtful that they will supplant the natural desire of woodpeckers to excavate. This is validated by the fact that many multiple cavity poles and trees exist, even though some pole cavities are completely unoccupied. Undoubtedly, biological ingenuity and the determination of utility companies will find a solution to the problem.

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Cavity-Nesting Bird Requirements and Response to Snag Cutting in Ponderosa Pine¹

Virgil E. Scott and John L. Oldemeyer¹

Abstract.--Cavity-nesting bird densities declined 53% when conifer snags were removed during a timber harvest on the Apache-Sitgreaves National Forest in Arizona. On an adjacent cutover area where snags were left standing the cavity-nesting bird population increased 25%. Cavity-nesting bird densities on an unharvested control plot increased 32%. Birds that nested in ponderosa pine snags were affected most by snag removal. Violet-green swallows² declined from 41 to 4 birds/100 acres after snags were removed and pygmy nuthatches declined from 32 to 15/100 acres. Two species responded significantly to the reduction in basal area: white-breasted nuthatches decreased and house wrens increased.

For nesting sites, cavity-nesting birds usually selected ponderosa pine (*Pinus ponderosa*) snags that were greater than 18 inches diameter breast high (dbh), dead 6 years and with at least 40% bark cover.

INTRODUCTION

Snags serve in a variety of ways as wildlife habitat. Cavities made by primary cavity nesters (those birds that excavate their own holes) provide nests and denning sites for secondary cavity users (those that nest in cavities but are unable to excavate holes) such as bats, squirrels, and several birds (Thomas et al. 1979). Snags are used by raptors, flycatching birds, and band-tailed pigeons (*Columba fasciata*) for such activities as hunting, feeding, loafing, or roosting (Scott et al. 1980). Invertebrates living in the dead wood and under bark provide food for some of the woodpeckers.

It has been shown that snags with heartrot (*Fomes* sp.) are selected by primary cavity-nesting birds for excavating nest holes (McClelland and Frissel 1975, Miller and Miller 1980), and that larger snags are used more frequently than smaller

snags (Bull 1975, Gale 1973, McClelland and Frissel 1975, Thomas et al. 1979). Mannan et al. (1980) reported that the density of hole-nesting birds was positively correlated with the mean dbh of snags on their study area in western Oregon. However, no general statement can be made for all birds since size of snags used for nest hole excavation varies with tree and bird species (Bull et al. 1980, Lanning and Shiflett 1983, Mannan et al. 1980, McClelland et al. 1979, and Scott et al. 1980). This report summarizes the characteristics of snags used by cavity-nesting birds in a forest dominated by ponderosa pine in Arizona and the response of birds to snag removal.

STUDY LOCATION AND METHODS

The 124-acre study area was in an oldgrowth ponderosa pine forest five miles west of Greer, Arizona, on the Apache-Sitgreaves National Forest. Ponderosa pine accounted for 83% of the tree stand which also contained Douglas-fir (*Pseudotsuga menziesii*) and limber pine (*Pinus flexilis*). Several small aspen (*Populus tremuloides*) clones were interspersed throughout the stand. The study area was divided into three plots. Plots A and B were selectively harvested; snags were cut on Plot A but not on Plot B. Plot C served as an uncut control. Eight bird surveys were conducted on each plot between 20 May and 30 June for 2 years before harvest and 2 years after

¹ Virgil E. Scott and John L. Oldemeyer are wildlife biologists (research), U.S. Fish and Wildlife Service, Denver Wildlife Research Center, stationed at Fort Collins, Colorado.

² Bird nomenclature follows the Thirty-fourth Supplement to the American Ornithologists' Union Checklist of North American Birds. Supplement to the Auk. Vol 99, No. 3, July 1982 and scientific names appear in Table 1.

harvest. Bird densities were determined by the spot map method (Kendeigh 1944) and compared by analysis of variance.

Basal area of live trees $\geq$ five inches dbh was determined by the plotless method (Grosenbaugh (1952). Trees were harvested in late summer and fall 1974 after bird surveys were completed. All conifer snags on the study area were measured and examined for use by cavity-nesting birds before timber harvest occurred.

RESULTS AND DISCUSSION

Basal area of live trees $\geq$ five inches dbh before timber removal was 110, 107, and 102 feet²/acre on Plots A, B, and C respectively (Scott 1979). Post harvest basal area on A and B was 51 and 64 feet²/acre respectively. Basal area in Plot C was unchanged.

There were 4.6 conifer snags/acre $\geq$ 7 inches dbh in Plot A before harvest and all were cut during timber harvest and most were left on the ground. After timber harvest 14 aspen snags $\geq$ 5 inches dbh (0.3/ac) remained. On Plot B there were 6.1 conifer snags/acre before harvest. Some snags were accidentally knocked down during timber harvest and some were blown over; 4.1 conifer snags/acre remained. After timber harvest 29 aspen snags $\geq$ 5 inches dbh (0.8/ac) remained on Plot B. Plot C had 4.0 conifer snags/acre in 1973 and 3.6 in 1976; no aspen snags $\geq$ 5 inches dbh occurred in Plot C.

Birds usually selected ponderosa pine snags greater than 18 inches dbh, those had been dead $\geq$ 6 years, and those with at least 40% bark cover for nest sites and 71% of the snags meeting these criteria had holes made by cavity nesters. Twelve percent of the snags $\geq$ 8 inches dbh and dead $\leq$ 5 years had holes whereas 62% of those dead $\geq$ 6 years had been used by cavity-nesting birds. Nearly all of the cavity nests found in ponderosa pine were in snags. Those cavity nests found in living trees were in dead portions of the tree (ie. dead tops or a dead strip resulting from lightning strikes). Larger snags tended to have more holes and were used more frequently than smaller snags. Tall snags (>45 feet) were used at about the same frequency as shorter ones (<45 feet) but more holes were present in the taller snags. There were 2.6 snags/acre with cavities and 75% of the snags containing cavities were $\geq$ 19 inches dbh. Holes were present in 28% of snags <19 inches dbh and 54% of those $\geq$ 19 inches.

Densities of all birds before harvest ranged from 225/100 acres on Plot C to 303/100 acres on Plot B (table 1) and were not different ($P<0.05$) among plots. Within treatments, the posttreatment bird densities were not different from pretreatment. Density of foliage-nesting birds did not change after harvest. Ground-nesting birds increased on all plots but the percentage increase was least on the Plot C. Most of the numerical

increase in ground nesting birds was related to reduction in basal area on Plots A and B.

Density of cavity-nesting birds was 53% lower on Plot A after timber harvest whereas density increased on Plots B and C. Some bird species within the cavity-nesting guild responded independently but the overall response in density was positively correlated ($r=0.72$) to the number of snags in the plots.

Some birds occurred in numbers too small or in too few plots and no inferences could be made about the effect of timber harvest on their density (i.e., American kestrels, yellow-bellied sapsuckers, downy woodpeckers, hairy woodpeckers, three-toed woodpeckers, brown creepers, and mountain bluebirds). We found nests of American kestrels, three-toed woodpeckers, and violet-green swallows only in ponderosa pine snags; whereas, nests of Williamson's sapsuckers and hairy and downy woodpeckers were found only in aspen. Scott et al. (1980) reported violet-green swallows nesting in both aspen and conifer snags. We also found northern flickers, mountain chickadees, and white-breasted nuthatches nesting in aspen and ponderosa pine snags. One pygmy nuthatch was observed nesting in an aspen snag on Plot A after snag removal.

Densities of three species did not respond with timber harvest: Williamson's sapsuckers, mountain chickadees, and western bluebirds (table 1). Greatest densities of Williamson's sapsuckers were found in the control plot both before and after harvest, and densities were somewhat lower in all plots after harvest. Mountain chickadees responded in a similar manner, whereas western bluebirds increased slightly, but not significantly so, after harvest in all plots. The remaining aspen (trees and snags) probably provided nesting habitat for these species. We observed one pair each of pygmy nuthatch, Williamson's sapsucker, and western bluebird nesting in one aspen snag on Plot A after timber harvest. Western bluebirds usually nest near openings or in more open woodlands and the timber harvest created this type of habitat.

Two species responded significantly to the reduction of basal area (table 2). White-breasted nuthatches decreased significantly in Plots A and B, where post-harvest density averaged 20% of the pre-harvest density. Density of western flycatchers followed a similar, though non-significant, pattern to white-breasted nuthatches. Although white-breasted nuthatches are cavity nesters, their decrease was probably due to the decrease in standing timber. House wrens, on the other hand, increased in Plots A and B after harvest where its post-harvest density averaged 222% greater than pre-harvest density. This increase was probably due to the increase in slash piles or brush found in the cutover areas.

Three species decreased significantly on Plot A with the reduction in snag density (table 2); northern flicker, violet-green swallow, and pygmy

Table 1.--Number of cavity-nesting birds/100 acres in a ponderosa pine study area before and after timber harvest. Densities are means of surveys conducted 2 years before and 2 years after timber harvest. Comparisons were made by ANOVA (NE = not examined, NS = non-significant, S = significant $P \leq 0.05$).

	Results of ANOVA	Plot A Timber Harvested Snags Cut		Plot B Timber Harvested Snag Left		Plot C Timber Not Harvested	
		Before	After	Before	After	Before	After
American kestrel (<i>Falco sparverius</i>)	NE		<1	3	5	0	0
Yellow-bellied sapsucker (<i>Sphyrapicus varius</i>)	NE	2	<1	3	3	0	0
Williamson's sapsucker (<i>S. thyroideus</i>)	NS	9	4	8	5	10	7
Downy woodpecker (<i>Picoides pubescens</i>)	NE	0	2	1	0	1	<1
Hairy woodpecker (<i>P. villosus</i>)	NS	5	3	<1	4	2	7
Three-toed woodpecker (<i>P. tridactylus</i>)	NE	3	<1	3	3	2	<1
Northern flicker (<i>Colaptes auratus</i>)	S	10	5	9	12	11	15
Western flycatcher (<i>Empidonax difficilis</i>)	S	7	2	11	8	10	10
Violet-green swallow (<i>Tachycineta thalassina</i>)	S	41	4	50	77	29	46
Mountain chickadee (<i>Parus gambeli</i>)	NS	11	9	14	11	15	10
White-breasted nuthatch (<i>Sitta carolinensis</i>)	S	7	2	8	<1	10	7
Pygmy nuthatch (<i>S. pygmaea</i>)	S	32	15	37	45	27	40
Brown creeper (<i>Certhia americana</i>)	NE	2	1	5	<1	0	7
House wren (<i>Troglodytes aedon</i>)	S	8	11	1	18	0	<1
Western bluebird (<i>Sialia mexicana</i>)	NS	2	5	5	7	2	5
Mountain bluebird (<i>S. currucoides</i>)	NE	<1	2	9	11	0	3
Cavity nesters	S	139	66	167	209	119	157
Foliage nesters	NS	105	83	98	129	81	79
Ground nesters	S	31	51	38	67	25	48
Total Birds	S	275	200	303	405	225	284

Table 2.--Density of birds (number/100 ac) related to basal area and to snag density in a ponderosa pine forest in Arizona. Contrasts based on Scheffes' procedure.

	Density related to basal area		Density related to snag density	
	Plots A, B, and C before harvest and C after harvest (high basal area)	Plots A and B after harvest (low basal area)	Plot A after harvest (snags removal)	Plots B and C after harvest (snags not removed)
Northern flicker	11.3	8.5	5.0	13.5 *
Western flycatcher	9.5	5.0	2.0	9.0
Violet-green swallow	41.5	40.5	4.0	61.5 *
Mountain chickadee	12.5	10.0	9.0	10.5
White-breasted nuthatch	8.0	1.5 *	2.0	4.0
Pygmy nuthatch	34.0	30.0	15.0	42.5 *
House wren	2.5	14.5 *	11.0	9.5
Western bluebird	3.5	6.0	5.0	6.0
Cavity nesters	145.5	137.5	66.0	183.0 *
Foliage nesters	90.8	106.0	83.0	104.0
Ground nesters	35.5	59.0	51.0	57.5

* Probability of observing differences in means of this magnitude were $\leq 0.05\%$.

nuthatch. Violet-green swallows and pygmy nuthatches depended heavily on ponderosa snags for nest sites. No other species followed an increasing or decreasing trend that seemed related to removal of snags; however, the cavity nesting guild decreased significantly when the density in Plot A (with snag removal) was compared to the post-harvest densities of Plots B and C. Cavity-nesting birds were affected by removals of conifer snags on Plot A although there were 0.3 aspen snags/acre ≥ 5 inches after timber harvest. Those birds that nested in ponderosa pine snags before harvest (violet-green swallows, pygmy nuthatches, and three-toed woodpeckers) were most affected by snag removal.

MANAGEMENT SUGGESTIONS

Cavity-nesting bird nest site requirements vary with the species since the larger birds physically require larger snags for hole excavation than do the smaller birds. Bull and Meslow (1977) suggested that snags ≥ 20 inches dbh should be retained for pileated woodpeckers (*Dryocopus pileatus*). Smaller birds, such as chickadees (*Parus* sp.), can use snags as small as six inches dbh (Scott et al. 1980).

Balda (1975) suggested that 2.7 snags/acre are necessary to maintain maximum densities and natural species diversity of secondary cavity nesters in the ponderosa pine forest. Cunningham et al. (1980) found that 2.1 snags/acre might be sufficient for secondary cavity nesters at natural levels. We found evidence of cavity nesting or roosting in 2.6 snags/acre in this uncut ponderosa pine forest which should have been at natural levels. Cunningham et al. (1980) reported that 75% of the nests located were in snags greater

than 23 inches dbh. We found that 75% of the snags with holes were ≥ 19 inches dbh. Holes were present in 28% of the snags ≤ 18 inches dbh whereas 54% of those snags ≥ 19 inches dbh had holes. For those snags that had been used by birds, the larger snags also had more holes/snag (3.8) than the smaller snags (2.8). Larger snags also remain standing longer than smaller snags (Cline 1977). If two to three snags/acre are accepted as a management goal in the ponderosa pine type, then all should be ≥ 19 inches dbh in order to fulfill the cavity-nesting bird's requirements. Trees with dead tops or dead portions in the trunk provide nesting sites for cavity nesters and if retained in the forest, can provide cavity nesting opportunities over a long period of time.

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Problems in Snag Management Implementation — A Case Study¹

Edward W. Styskel²

Abstract.--Providing suitable snags over time for dependent wildlife within intensively managed forests is an extremely complex task. Problems encountered in achieving this goal include: (1) moderate responsiveness by accountable personnel; (2) determining and following snag status; (3) minimizing timber yield reductions; (4) imprecise "longevity" data for standing snags; and (5) protecting snags and live replacements from natural and man-caused loss. Techniques used to overcome some of these obstacles are discussed.

INTRODUCTION

Efforts to intensively manage commercial forest land of National Forests in the western United States on an "even-aged" basis have made complex the task of providing suitable snags over time for dependent wildlife. Specifically, plans for the Deschutes National Forest in central Oregon have scheduled lodgepole pine, ponderosa pine, and mixed conifer forest stands for conversion to intensive timber management within 20, 40, and 50 years, respectively. Furthermore, rotation ages for these stands will be relatively short, at approximately 80, 135, and 120 years.

Snag management goals for the Forest have been established based on the concept of "maximum potential population" offered by Thomas, et al. (1979). Obstacles in achieving these goals have been numerous and difficult. Some have been surmounted; others are still unresolved.

This paper reports on what problems have been encountered (thus, could be expected by others implementing snag management), and how some were concluded.

PROBLEMS

The transition from establishment of policy concerning the management of snags, first set forth on the Forest in 1973, to implementation on-the-ground has been slow but steady. First

efforts concentrated on protecting existing snags. Then, additional attention was given to reserving some live trees for future snag replacements. Now, systematic calculation of the number and size of live trees for snag replacements over a managed forest stand rotation is undertaken, based upon growth predictions and estimated snag standing longevity.

Responsiveness

This transition has bridged several obstacles, the first of which has been moderate responsiveness from personnel accountable for getting the job done. This problem is manifested at two hierarchical levels on a Forest--the line officers (Forest Supervisor and District Rangers) who establish program direction, and the project work force who carry out this direction.

Exceptional are those line officers who can place equal priority on providing snags for wildlife and meeting annual timber sell targets, when the latter is a performance appraisal element upon which the agency measures their managerial ability, and the former is not. Until such time as performance appraisals relate equally to all phases of National Forest management (i.e. meeting all targets of the Forest Plan, instead of singling out specific ones such as timber volume), the barrier is still potentially there.

Project workers who perform the details of project layout, whether it be timber sales, timber stand improvement, forest fuels treatment, or other impacting activities, may view snag management requirements as obstacles to full achievement of their functional goals. This is compounded by the volume of similar functional "impediments", such as visual quality, archeologic/historic protection, and others. Often, field-going project personnel are sea-

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²Edward W. Styskel is Forest Wildlife Biologist, Deschutes National Forest, Bend, Oreg.

sonal employees with limited personal ownership in determining these specific goals.

Proper emphasis from the line officer to the project work force is essential in stimulating these personnel to achieve all Forest goals, including those dealing with snag management.

Snag Status

Another snag management problem is determining and following the status of snags project area by project area. This difficulty is magnified as the area of perspective is enlarged to an entire drainage, Ranger District, or National Forest.

Special snag inventories are time-consuming, and therefore expensive.

Stand examination data, usually collected by foresters for assessing forest stand conditions, offer a reasonable alternative. Owing to regularly low snag densities and small plot size, stand exam plot frequency usually has to be increased to diminish exaggeration of the real-life situation.

It should be recognized that both techniques are a measurement of one point in time and subject to rapid change from natural phenomena and human activities.

Tabulation for monitoring snags and live replacements reserved for wildlife can best be accomplished during the timber marking stage in timber sale preparation. Tally records are recorded in the field which document the number, size, species, and successional condition (Thomas, et al. 1979) of snags or live replacements reserved for wildlife.

Site specific storage and retrieval of this data is necessary in order to be able to track these allocations for future land management decisions. In the Pacific Northwest Region of the U.S. Department of Agriculture--Forest Service, the TOTAL RESOURCE INFORMATION (TRI) System provides an automated system capable of handling this data by management "cell".

Minimizing Timber Yield Reduction

Minimizing timber yield falldown due to wildlife tree requirements is still another hurdle. Two concerns have developed--the retardation of growth on crop trees from reserved live replacements, and the genetic character of these reserved live trees.

McDonald (1976) reports in a California study that ponderosa pine seed trees had an inhibitory effect on seedlings beneath them. Live tree replacements could equally be expected, then, to negatively influence predicted timber growth and subsequent yield. Because of this effect, estimated growth loss in managed stands on the Deschutes National Forest is thought to be significant--perhaps as high as

12 percent.³ Timber volume loss for the recommended densities and sizes of snags to support 60 percent of the maximum potential population of primary⁴ excavators account for an additional 6 percent.

Often, live trees recommended by biologists for future snag replacements possess characteristics of genetic inferiority for maximum growth potential. Because anticipated timber growth and yield are usually predicated on growing genetically superior trees, these goals frequently collide.

Reducing these conflicts was the initiative for utilizing the technique of "clumping", whereby $\frac{1}{2}$ acre parcels were reserved intact within every 8 to 12 acres of cutting unit in lodgepole pine forest (fig. 1).⁵ The desired characteristics of these clumps are defined carefully to assure that the proper density and sizing of snags and live replacements are available.

Assumptions are made that the clumps: (1) satisfy distributional requirements based on estimated territory sizes of most primary excavators (Thomas, et al. 1979); (2) reduce the



Figure 1.--"Clumping" of reserved snags and live tree replacements.

³Smith, Tony. 1982. The effect of the proposed Deschutes National Forest's snag policy on the growth of managed stands. Unpublished report. Deschutes National Forest, Bend, Oreg.

⁴Deschutes National Forest. 1982. Managed yield tables for the Deschutes National Forest Land Management Plan. Unpublished process records. Deschutes National Forest, Bend, Oreg.

⁵McEwan, Linda. 1983. Personal conversation. Deschutes National Forest, Crescent, Oreg.

inhibitory effect of evenly distributed live tree replacements; (3) diminish the widespread influence of genetically inferior or diseased live replacements on seedling crop trees; (4) lessen blowdown loss experienced by single trees exposed after forest canopy removal; (5) shrink wildlife tree losses associated with other forest activities; and (6) provide habitat values for other wildlife. Monitoring over time will determine the validity of these assumptions.

Snag Standing Longevity

Knowledge of the standing "life expectancy" of snags is critically significant in determining how many live tree replacements must be reserved over a managed forest rotation to meet established goals. Few studies have been specifically designed to collect the kind of data a biologist might desire. Interpolation from research conducted with other objectives in mind is often necessary, and the more localized the better.

Factors including soil type, site productivity, climate, heartwood/sapwood ratio, the incidence of insects or disease, and others have been identified by Keen (1955) as influencing the rate of snag fall. To refine the longevity estimates used on the Forest, these factors will be measured in snag longevity monitoring efforts beginning this year.

Wildlife Tree Protection

Physical protection of reserved snags and live replacements is the final obstacle. Windthrow, and land management activities such as logging, forest fuel treatment, timber stand improvement, prescribed burning, and public firewood cutting, are all known sources of attrition.

It has been established that snag attrition occurs from windthrow, and is influenced by bole diameter--large diameter snags remaining upright longer than smaller ones (Dahms 1949, Lyon 1977). Determination of this loss is paramount to calculating snag and live replacement needs for areas where snag retention is planned. For example, some areas of the Forest have exhibited reductions in evenly distributed reserved snags of 25 percent for 20-inch or greater dbh snags, and 75 percent for less than 20-inch dbh snags, immediately after canopy removal by clear-cut or shelterwood.

Snag hazards to worker safety and fire protection in woods operations have prompted State Laws and Administrative Rules which require snag felling for reasonable hazard control. The consequences of these requirements can be moderated with careful attention to project design and wildlife tree position. For example, wildlife trees would not be positioned where obvious hazard to log landings or proposed road locations would jeopardize their retention.

While the felling of hazardous snags in timber harvest is a step backwards in terms of

snag management goals, this loss, and that from other causes, can often be mitigated with timber sale generated Knutson-Vandenberg funds to artificially create or manipulate snags. Such plans are underway on the Forest to accelerate snag formation by various techniques, including fire-scarring by piling and burning logging debris at the base of live snag replacements, and topping with explosives (Bull, et al. 1981) or cutting.

The latter technique was successfully contracted this spring on snags and live replacements at a cost of \$45 per tree.⁶ Ponderosa pine with dimensions of 18 to 26 inches dbh averaging about 80 feet tall were sawn off at a height of approximately 30 to 50 feet. The live replacements were topped to retain just enough live foliage for the tree to stay alive, the assumption being that a diminished live crown would be more windfirm and less influential on understory retardation and the spread of dwarf mistletoe.

Logging (or thinning) debris disposal and vegetative manipulation accomplished by prescribed burning may consume snags and down logs without pre-planned safe-guards. Loss of snags or live replacements due to post-sale activities has occurred because attention to snags often does not carry through to these stages of timber management. The land manager must learn to think about snags in all types of management activity before this short-circuit can be remedied.

Uncontrolled public firewood cutting can have significant consequences upon the retention of snags for wildlife, especially where relatively flat and open terrain or extensive road systems allow easy vehicular access. Land managers can control this activity, though, to lessen the influence on wildlife trees.

First, a permit system, the provisions of which are legally enforceable and require public user contact with the manager, is requisite. Protection of wildlife trees must be considered in specifying the requirements of the permit. For example, specifications on permissible tree species or diameter, areas open to cutting, or snags with evidence of wildlife use or protective signing may be necessary.

Public education of the potential for conflict between firewood cutting and maintaining snag habitat for wildlife can occur at the time of permit acquisition, and with Public Service Announcements during the woodcutting season.

Violation of permit provisions on the Deschutes National Forest is punishable through criminal citation and fine. In addition, mitigative damages can be assessed against violators for the cost of replacing the felled snag. When

⁶Corn, Don. 1983. Personal conversation. Deschutes National Forest, Sisters, Oreg.

available, a suitable live tree of similar dimensions would be killed, with the damage assessment being the cost of artificially inducing mortality, plus the commercial value of the tree. Where live tree replacements are unavailable, the damage assessment would be the cost of constructing, installing, and maintaining suitable nesting and perching structures.

In areas of excessive vulnerability to firewood cutters, "armoring" of wildlife trees is a productive technique. Twisted-wire fence stays nailed on the snag (fig. 2) have effectively protected assailable snags at a cost of about \$3.50 per snag for materials and labor. The narrow stays become virtually invisible from

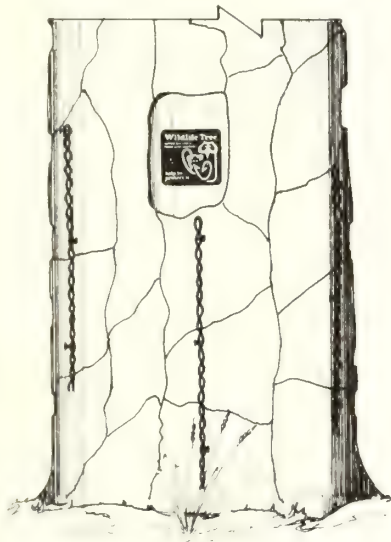


Figure 2.--"Armoring" of tree trunk. Three or four stays, offset to extend height of bole protection, are secured by bent-over nails in sound wood.

a short distance, making this technique suitable even in visually sensitive areas.

CONCLUDING REMARKS

While the obstacles to providing suitable snag habitat for dependent wildlife are both diverse and substantial, it is premature to say they are insurmountable. Successful efforts must recognize these problems, receive full commitment to their resolution, be innovative and aggressive in dealing with potential solutions, and closely monitor the results.

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Implications of Snag Policies on Management of Southwestern Ponderosa Pine Forests¹

Peter F. Ffolliott²

Abstract.--The Southwestern Region of the USDA Forest Service is providing habitat for snag-dependent wildlife species in ponderosa pine (*Pinus ponderosa* Laws.) forests. To evaluate alternative snag retention policies, study areas representing five silvicultural treatments and virgin conditions were evaluated to determine whether or not they met the policies under present conditions, and if not, whether or not policies would be met through natural mortality in the future.

INTRODUCTION

Southwestern ponderosa pine snags are an important habitat component for cavity-nesting wildlife species. At least 49 species of birds, along with the 10 species of mammals and numerous species of insects and herpetofauna, use tree cavities in southwestern forests (Scott and Patton 1975, USDA Forest Service 1977). These cavity-nesters depend on snags and dead portions of live trees for denning, roosting, feeding, and nesting cover. Sixty-three percent of the birds and three-fourths of the mammals that are snag-dependent in southwestern forests are insectivorous (USDA Forest Service 1977). These birds and mammals are often credited with insect control that helps to maintain a healthy ecosystem (Thomas et al. 1975).

Prior to recent years, snags were viewed as potential fire hazards, harborers of disease, and worthless space fillers (McClelland and Frissell 1975). However, in a change of policy, the Southwestern Region of the Forest Service is to provide adequate habitat to maintain self-sustaining populations of snag-dependent wildlife species (USDA Forest Service 1977).

To provide snags to perpetuity to ensure viable populations of snag-dependent wildlife species, it could become necessary to sacrifice timber production. Therefore, a study was undertaken to determine; (a) whether or not snag retention policies could be met solely through natural mortality; and (b) whether or not timber

volumes would be lost and revenues foregone if snags were artificially created.

STUDY AREAS

Southwestern ponderosa pine forests exist in uneven-aged stands of small, even-aged aggregates ranging from a few trees to stands of several acres (Schubert 1974). Cutting practices imposed in these forests involve a variety of silvicultural treatments undertaken to achieve a variety of multiple use objectives.

Data were obtained from study areas representing different silvicultural treatments, including the Beaver Creek Watersheds, the Heber Watersheds, and the Castle Creek Watersheds (fig. 1). Additionally, data were gathered on study areas representing virgin conditions, including the Castle Creek Watersheds, and the Fort Valley and the Long Valley Experimental Forests.

Snag retention management alternatives were examined on 10 study areas representing five silvicultural treatments; shelterwood-seed tree cut, shelterwood-stripcut, group selection cut, thinning-patch cut, and uniform thinning (table 1). The virgin forests studied provided a reference. Clearcut treatments were not analyzed, since this treatment precludes snag retention.

METHODS

Snag retention policies of one, two, or three snags per acre were examined under present conditions on the study areas, and under simulated conditions at the end of the 20-year period. Snags were defined as standing dead trees at least 12 inches in diameter and 10 feet in height. No differentiation was made between "hard" snags, those composed of sound wood, and "soft" snags, those characterized by advanced decay and

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²Peter F. Ffolliott is Professor, School of Renewable Natural Resources, University of Arizona, Tucson, AZ.

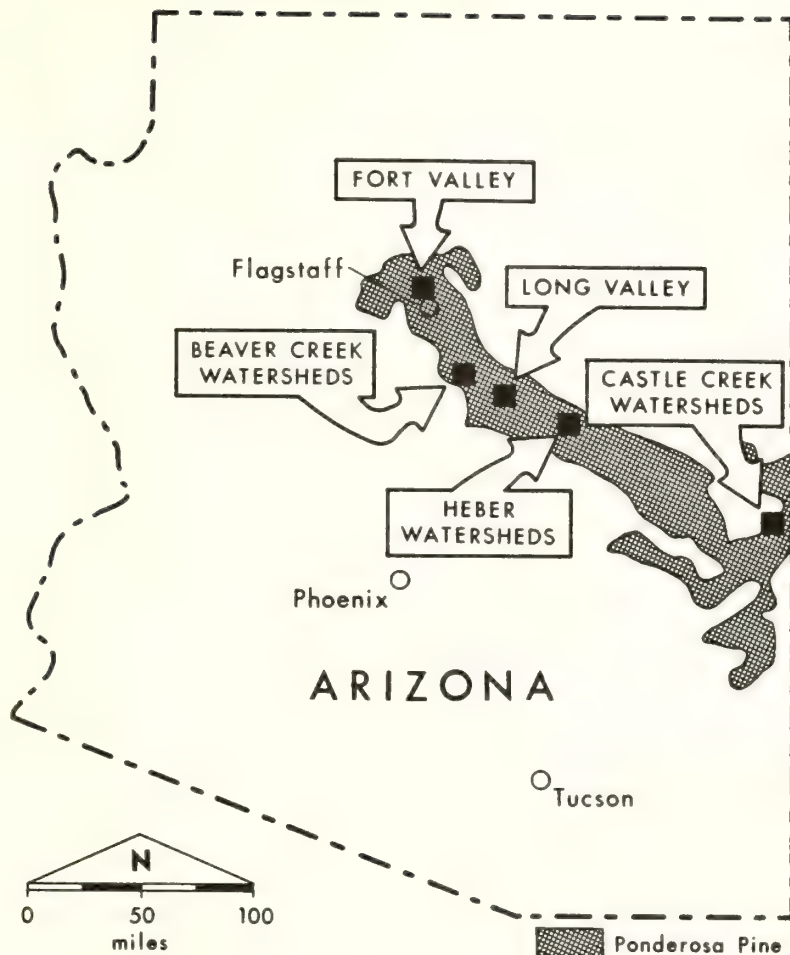


Figure 1. Location of study areas.

deterioration. Twenty years was selected as the simulation period because it coincides with a "typical" cutting cycle in southwestern ponderosa pine forests (Schubert 1974).

To help determine whether or not snag retention policies can be met in the future, a computer simulation model called SNAG was developed. This model estimates natural tree mortality and snag retention in southwestern ponderosa pine forests through time, given inputs of current growing stock and, if available, existing number of snags. In this study, outputs from SNAG were used to determine whether or not the study areas would meet suggested snag retention policies through natural mortality.

Initially, it was determined whether or not snag retention policies could be met solely through natural mortality. To this end, initial forest inventories of the study areas were repeated to summarize current growing stock and existing number of snags. These summaries provided the information to examine the alternative policies under present conditions and to formulate inputs to SNAG to simulate conditions at the end of the 20-year period. If the policies were not

met through natural mortality, and if snags were artificially created, timber volumes lost and revenues foregone were ascertained.

To quantify possible timber volumes lost due to the creation of snags, it was necessary to define a "target" stand toward which forest management should be aimed. A balanced uneven-aged stand was selected as the "target" structure. To define this structure, three parameters were quantified; a "q" ratio³ of 1.3, a maximum tree diameter of 24 inches, and a residual basal area of 60 square feet per acre. Other quantifications of these parameters could have been made, or another "target" could have been selected. The "target" structure presented herein is simply illustrative.

After defining a "target" stand, any number of scenarios that specify when during the 20-year period snags are to be created, and what size of trees will be sacrificed could be developed to analyze timber volumes lost (Nowakowski 1980).

³de Liocount's "q" ratio reflects a decreasing geometric series of numbers of trees per acre for successive diameter classes.

Table 1.--Silvicultural treatments and study areas

Silvicultural treatment and study area	Size (acres)	Description
<u>Shelterwood-seed tree cut</u> Beaver Creek Watershed 8	1,892	Residual densities of 60 sq ft of basal area in size classes 10 in dbh and less, 70 sq ft in 12-22-in dbh classes; stands averaging 24 in in dbh and larger cut in shelterwood-seed tree system.
<u>Shelterwood-stripcut</u> Beaver Creek Watershed 14	1,267	One-third of area cleared in irregular strips averaging 60 ft wide; intervening leave strips thinned to 60 sq ft of basal area.
<u>Group selection cut</u> Beaver Creek Watershed 13	867	Residual density of 99 sq ft of basal area, in uneven-aged structure.
Heber Watersheds	134	Residual density of 98 sq ft of basal area, in uneven-aged structure.
<u>Thinning-patch cut</u> Beaver Creek Watershed 10	571	Irregular openings (1 to 10 acres); timber in leave areas cut in similar manner as Beaver Creek Watershed 8.
West Fork Castle Creek	900	One-sixth area cleared in patches, with remaining five-sixths cut to residual density of 65 sq ft of basal area, in uneven-aged structure.
<u>Uniform thinning</u> Beaver Creek Watershed 17	299	Residual density of 30 sq ft of basal area, in uneven-aged structure.
<u>Virgin forests</u> East Fork Castle Creek	1,163	Density of 134 sq ft of basal area, in uneven-aged structure.
Fort Valley Experimental Forest	76	Density of 175 sq ft of basal area, in uneven-aged structure.
Long Valley Experimental Forest	1,280	Density of 214 sq ft of basal area, in uneven-aged structure.

The one presented below represents a situation in which timber volumes lost are minimized.

Trees in surplus to the "target" stand structure, if present, would be those initially used to create snags. Of course, merchantable volumes lost by creating snags from surplus trees would have to be reflected by losses in timber volumes and revenues foregone at the time of harvesting. It was assumed that any timber harvesting operation would occur at the present time.

If additional trees were required to meet a policy, a sacrifice in growing stock prescribed by the "target" stand would be necessary. Unfortunately, this latter action would delay meeting

the conditions specified by the "target," resulting in additional, but unknown, costs. In this scenario, it was assumed that, if growing stock had to be sacrificed, snags would be created at the present time, starting with trees 12 inches in diameter. By starting with the smallest trees, less timber volumes would be lost to subsequent harvesting.

Calculations of revenues foregone were based on stumpage value of \$75 per thousand board feet of lumber. Future values of stumpage at the end of the 20-year period were calculated by the general compound interest formula at 5 and 10 percent. Revenues foregone represent approximated losses only, as these values will undoubtedly vary

with distribution of harvest volumes by size and grade.

RESULTS AND DISCUSSION

Analysis of snag retention policies met solely through natural mortality indicated that, under present conditions, none of the study areas subjected to silvicultural treatments met any of the suggested policies. In fact, only one of the virgin forests examined, the Long Valley Experimental Forest, met snag retention policies under present conditions, and this area met all of the policy standards.

Under simulated conditions at the end of the 20-year period, the areas subjected to the shelterwood-seed tree cut, the shelterwood-stripcut, and the group selection cut would only meet a snag retention policy of one snag per acre through natural mortality. Areas representing the other silvicultural treatments would meet none of the policies. All of the virgin forests would meet snag retention policies of one or two snags per acre and, of course, the Long Valley Experimental Forest would support three snags per acre.

From this analysis, virgin forests would meet a snag retention policy of one or two snags per acre through natural mortality at the end of the 20-year period. If three snags per acre were required, additional snags must be artificially created. Losses in timber volumes in virgin forests being managed for three snags per acre (and if these forests are to be harvested) would approximate 60 board feet per acre, mostly in trees 12 inches in diameter. Present value of this loss is \$4.50 per acre. Future values of this loss at the end of the 20-year period would be nearly \$12 per acre at 5 percent and approximately \$30.50 per acre at 10 percent interest rates.

The study areas subjected to the shelterwood-seed tree cut, the shelterwood-stripcut, and the group selection cut would generally meet a policy of one snag per acre through natural mortality over the 20-year period. However, if managed for two snags per acre, losses of approximately 115 board feet per acre would occur, primarily in trees 12 to 14 inches in diameter. Present value of this loss is almost \$8.75 per acre, and future values are about \$23 per acre at 5 percent and nearly \$58 per acre at 10 percent interest rates. If managed for three snags per acre, losses over the 20-year period would be 220 board feet per acre. Present value of this loss is \$16.50 per acre, while future values would be nearly \$44 per acre at 5 percent and \$111 per acre at 10 percent interest rates.

Study areas representing the thinning-patch cut and the uniform thinning silvicultural treatments would not meet any of the snag retention policies through natural mortality at the end of the 20-year period. Therefore, if managed for one snag per acre, losses would approximate 90 board feet per acre, presently valued at about \$7 per

acre. Future values of this loss would be \$18 at 5 percent and almost \$45.50 per acre at 10 percent interest rates. If managed for two snags per acre, losses would be 165 board feet per acre. Present value of this loss is approximately \$12.50 per acre, and future values would be in excess of \$32.50 at 5 percent and nearly \$83.50 at 10 percent interest rates. Finally, if managed for three snags per acre, losses would approach 280 board feet per acre, presently valued at \$21 per acre. Future values of this loss would be about \$56 at 5 percent and \$141 at 10 percent interest rates.

It must be emphasized that the study areas evaluated are illustrative only, since implementation of a given silvicultural treatment usually varies in its prescription. Therefore, the magnitudes of timber volumes lost and revenues foregone discussed are only general guidelines.

SUMMARY

Depending upon the snag retention policy followed, some southwestern ponderosa pine forests will meet the policy requirements at the end of a 20-year period through natural mortality. Other forests subjected to particular silvicultural treatments will require artificial creation of snags. As a result, timber production may be sacrificed.

To determine timber volumes lost and revenues foregone through artificial creation of snags, a "target" stand toward which forest management should be aimed must be defined. Also, the point in time when snags are to be created must be determined. Given this information, and assuming a specific interest rate, it is possible to estimate timber volumes lost and revenues foregone.

While the results of this study pertain to southwestern ponderosa pine forests, a similar approach could be helpful in evaluating snag policies with respect to timber volumes lost and revenues foregone in other forest types.

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Coarse Woody Debris and Debris-Dependent Wildlife in Logged and Natural Riparian Zone Forests — A Western Oregon Example¹

Steven P. Cline and Charles A. Phillips²

Abstract.--We conducted a reconnaissance study to determine some structural aspects of riparian zone forests and the effects of logging upon woody debris wildlife habitat. We also conducted a literature search to gather information upon the debris-dependent wildlife in riparian zone forests, and how they are influenced by timber management. This information was synthesized in a hypothetical example of snag management in the Coast Range of Oregon. We found that snag habitat of the larger woodpeckers was reduced by clearcutting and we predicted that shortened rotations in the future will reduce or even locally extirpate 20 bird and 5 mammal species. We calculated that the snag requirements of hole-nesting birds are not met using only snags in riparian zone buffer strips. An active program of dead tree management on upland areas is also necessary.

INTRODUCTION

Swanson et al. (1982) define the riparian zone functionally as the zone of direct physical, chemical and biological interaction between terrestrial and stream ecosystems. Riparian zone forests control the stream environment through shading, deposition of fine and coarse plant matter, stabilizing stream banks, and filtering dissolved nutrients and sediment (Meehan et al. 1977). Coarse woody debris from riparian zone forests shape channel morphology and controls routing of water and sediment storage. Riparian zone vegetation provides diverse wildlife habitat because of a land/water interface, multiple horizontal and vertical edges and multiple combinations of successional stages (Thomas et al. 1979).

Timber management is the major land use of forested mountains in western Oregon. Clearcut logging of riparian zone forests drastically changes the stream environment by initially reducing shade and organic matter inputs, adding unstable logging slash and destabilizing banks through yarding and root decay (Brown and Krygier

1970, Lammel 1972, Bryant 1980). Logging and road building can trigger landslides that enter channels, form debris torrents, and scour or "sluice out" the accumulated sediment and woody debris (Swanson and Lienkaemper 1978, Gresswell et al. 1979). The influence of logging upon the stream environment has long concerned fisheries and wildlife biologists, hydrologists and foresters (Narver 1971). Consequently, riparian zone buffer strips are now used to protect the stream environment and maintain the multiple functions of riparian zone forests (Steinblums 1978).

Riparian zone forests perform multiple functions. In this paper we focus upon one of these: habitat for wildlife dependent upon standing and fallen dead trees. Dead tree management on upland slopes conflicts directly with timber management (Meslow 1978, Cline et al. 1980). Management for dead trees in riparian zone forests may avoid some of the direct conflicts with intensive forestry and coordinated effectively with the established program of buffer strip management. We established two study objectives: (1) describe riparian zone forests, their woody debris characteristics, and their debris-dependent wildlife under both natural conditions and management, and (2) evaluate the importance of buffer strips to dead tree habitat management.

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²Steven P. Cline is a Research Assistant, Department of Forest Science, Oregon State University, Corvallis, Ore., and Charles A. Phillips is a Wildlife Biologist, United States Forest Service, Siuslaw National Forest, Corvallis, Ore.

STUDY AREA

We studied the riparian forests along the South Fork of Rock Creek, a fourth-order stream draining 13.5 km² of the Siuslaw National Forest, central Coast Range of Oregon. About 70% of the upland is covered by mature and old-growth

Douglas-fir (*Pseudotsuga menziesii*) forests with Douglas-fir plantations covering the remaining 30%. In this watershed the drainage density is 3800 m/100 ha and the riparian zone forest averages 40 m wide; therefore, about 15% of the Rock Creek watershed supports riparian zone vegetation.

METHODS

In this study we attempted to interface research and management, a relationship we believe requires cultivation. During this process we exposed large gaps in our empirical knowledge. We lacked wildlife abundance data in relation to woody debris characteristics, especially for woody debris in managed forests. Consequently, we were forced to use general relationships between woody debris characteristics and species use to predict the effects of timber management upon debris-dependent wildlife. We could not predict accurate changes in population levels using this method, only trends. Furthermore, a limitation with any prediction is that we, nor anyone, can predict the exact course of forestry practices.

Reconnaissance Study

Tree fall is one functional link between forests and streams. During reconnaissance of the Rock Creek watershed we observed that the source of most in-stream debris was within 30 m of the channel edge. Consequently we defined riparian forests as those forests growing within a 60-80 m zone centered on stream channels. The zone includes vegetation growing in the channel, on the floodplain, and on the bottom of upland slopes, i.e., toeslopes.

We laid out a large plot 50 m long by 60 m wide centered on the channel and divided it into 10 m² subplots. We then made a complete inventory of trees, snags and logs and recorded: subplot number, geomorphic unit (channel, floodplain, and toeslope), species, decay stage, crown class and length, dbh or end diameter, length or height, and wildlife use. In this study a snag was any standing dead tree ≥ 15 cm dbh and ≥ 1.5 m tall, and a log was any down tree or piece thereof, ≥ 15 cm diameter at the small end and ≥ 1 m long.

To determine the effect of logging upon snags and logs within riparian zone forests we selected sites increasingly disturbed by timber management activities: (1) untreated old-growth riparian zone forests (control, n = 2), (2) salvage logged and the stream channel sluiced (n = 1), (3) clear-cut logged leaving a narrow discontinuous buffer strip and channel sluiced (n = 1), and (4) clear-cut logged without a buffer strip (n = 1). Woody debris was compared between treated and control forest.

Literature Synthesis

Data from our reconnaissance study was supplemented with pertinent literature, unpublished data and manuscripts, and working documents of the

Siuslaw National Forest. This information was synthesized as a hypothetical example of a 100-ha snag management area within the South Fork of Rock Creek watershed.

RESULTS

Natural Forests

During development riparian forests changed from predominately deciduous to coniferous trees (fig. 1). In successional stages 1 and 2 red alder (*Alnus rubra*) formed dense, nearly pure stands along streamside zones, especially if the stream channel had been disturbed by debris torrents³. During stages 3 and 4 red alder declined because of suppression by riparian and upland forests. In stages 5 and 6 the overstory was mixed with Douglas-fir, western red cedar (*Thuja plicata*), and western hemlock (*Tsuga heterophylla*) and the understory with western yew (*Taxus brevifolia*) and bigleaf maple (*Acer macrophyllum*).

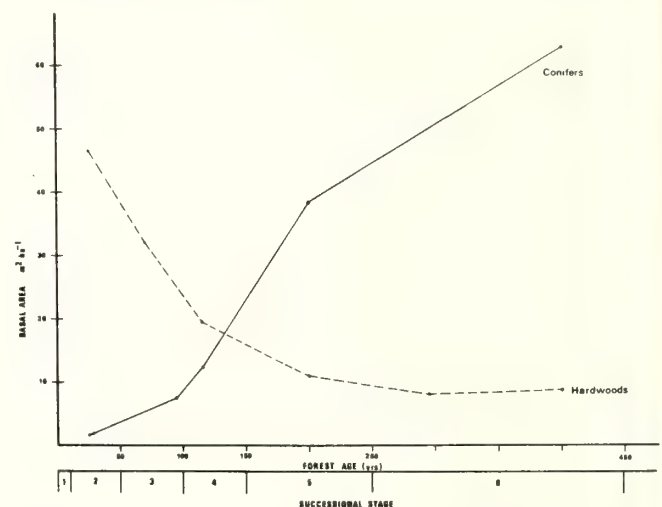


Figure 1.--Tree basal area in successional stages of riparian zone forests, western Oregon.

The structure of riparian zone forests was substantially influenced by stream width because light penetration to the riparian zone increased with stream width, and larger streams had greater ability to disrupt forest succession (fig. 2). Consequently riparian vegetation growing on or below the floodplain of some third order and larger streams developed independently from forest vegetation above the floodplain. For example, red alder and willow (*Salix* spp.), both early successional species, were maintained with older riparian and upland forests along larger streams (fig. 2C). In the South Fork of Rock Creek, however, third and fourth order channels composed only 12% of the total stream length; therefore, red alder and willow were ephemeral in most of this watershed.

³Cline, S. P. and F. J. Swanson. Development of riparian and hillslope vegetation after clear-cutting, western Oregon (in preparation).

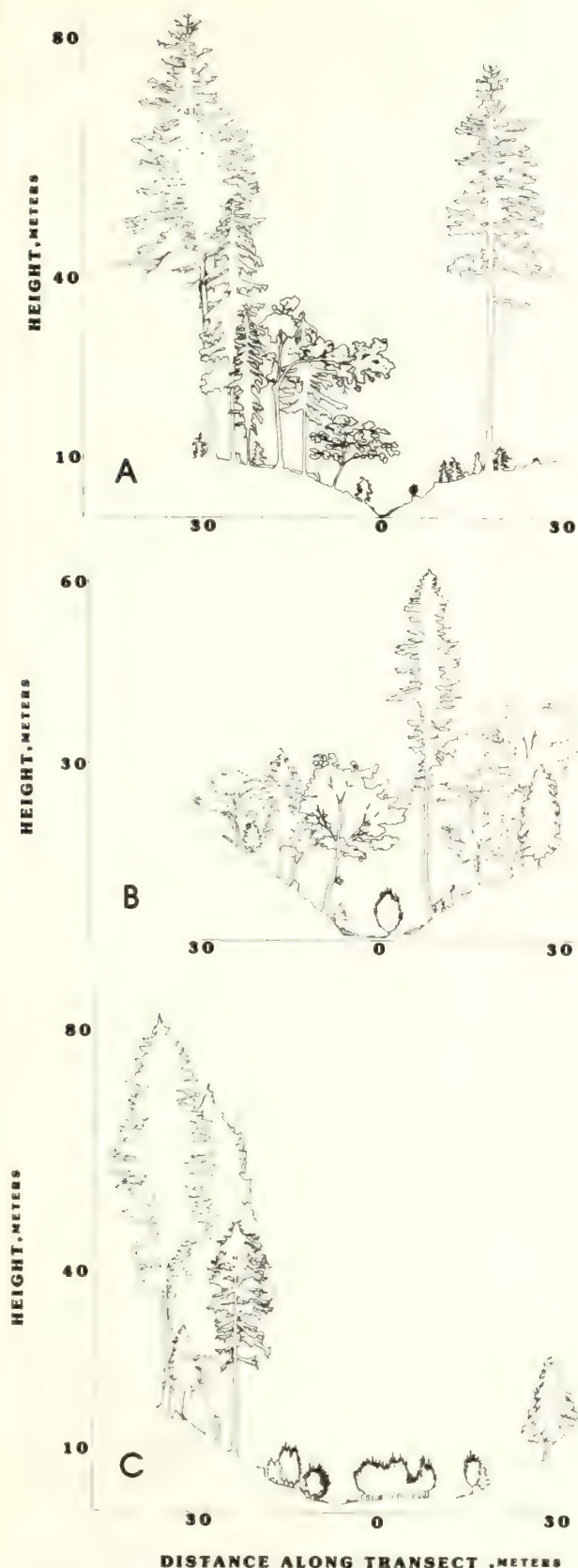


Figure 2.--Examples of cross-sections through old-growth riparian zone forests along (A) first, (B) third, and (C) fourth order streams, Oregon Coast Range. The number of trees represent an average for a 10 m wide cross-section ($n = 5$).

Basal area of snags increased with forest age, and snags changed from predominately deciduous to coniferous (fig. 3). Relative to total basal area (tree plus snag), snag basal area increased from 3 to 11% in successional stage 1 and 6, respectively. Snag density averaged 240, 37, 5, 4, and 12 ha^{-1} , and snag dbh averaged < 15, 27, 38, 64 and 102 cm in successional stages 2-6, respectively. In the Oregon Coast Range snag densities were lower in riparian zone forests than upland forest of the same successional stage (Cline, 1977). Diameters of logs along streams averaged 32, 42, 59, and 62 cm in successional stages 3-6, respectively; the corresponding log volumes were 233, 370, 720, and 1057 $\text{m}^3 \text{ha}^{-1}$ (Cline 1977). In seral stages 1-3 there were two sources of log habitat: snag break-up and residual logs carried over into the new forest after wildfire or logging (Swanson and Lienkaemper 1978, Cline et al. 1980). In stages 4-6 a third source of logs was tree uprooting (Graham 1982). The large logs produced in stages 4-6 are important to stream ecosystems because larger logs form longer lasting debris dams in streams, longer logs are required to form debris dams as stream width increases, and large logs form residual in-stream debris dams after logging or wildfire (Swanson et al. 1976, Swanson and Lienkaemper 1978, Bilby and Likens 1980).

On the Siuslaw National Forest approximately 80 species of snag and log-dependent wildlife use riparian zone forests - 43 birds, 24 mammals and 13 reptiles and amphibians⁴. The total number of species increased dramatically from successional stages 1 to 6, especially bird species numbers which increased nearly 400% (fig 4). Meanwhile the number of mammal and reptile and amphibian species increased 50 and 0%, respectively. The number of wildlife species using snags only, logs only and both snags and logs was 48, 24, and 8, respectively. Birds were snag-dependent and reptiles and amphibians were log-dependent, but among mammals some species

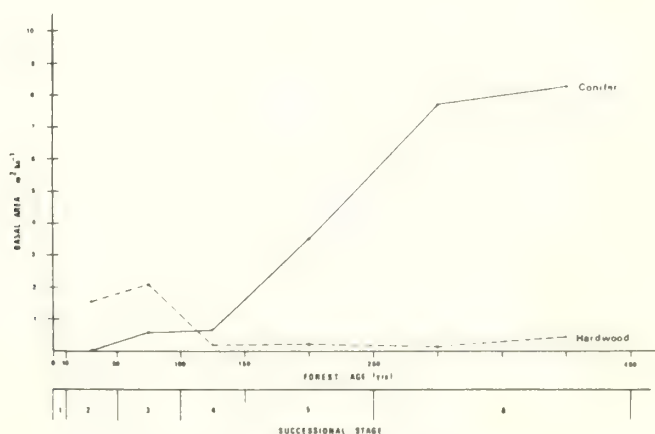


Figure 3.--Snag basal area in successional stages of riparian zone forests, western Oregon.

⁴Phillips, C. A., and others. 1980. Wildlife habitats and species management relationships program, Vols. I-IV. USDA Forest Service. Pacific Northwest Region. On file at Siuslaw National Forest, Corvallis, Ore.

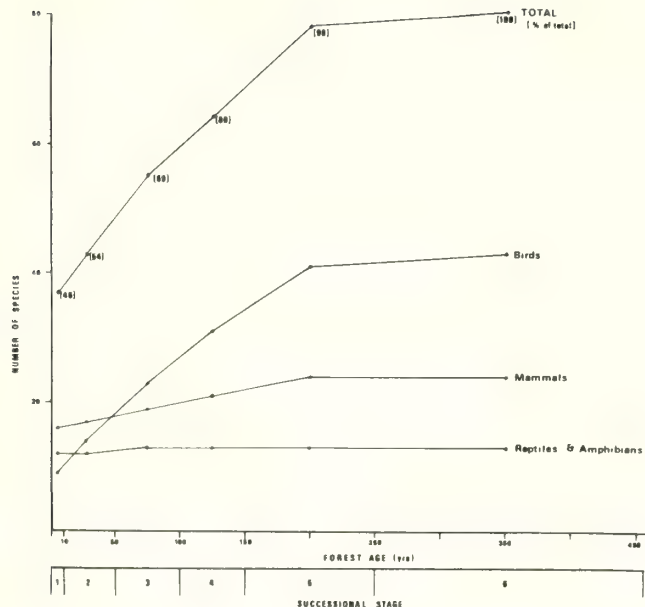


Figure 4.--Number of species of debris-dependent wildlife in successional stages of riparian forests, western Oregon.

used snags only, logs only or both. All wood decay stages were used by debris-dependent wildlife in riparian zone forests, but the percentage of species using decay stage 1 (no decay) and stage 5 (advanced decay) was lower than use of stages 2-4 (moderate decay) (table 1). This pattern of preferential use was evident for mammals and birds. Stage of decay influences not only the type of wildlife use, but also the degree of use (Mannan et al. 1980).

Table 1.--Frequency distribution of snag- and log-dependent species by wood decay stage, western Oregon. Feeding and breeding use only¹.

Vertebrate group	Distribution by decay stage, %				
	1	2	3	4	5
Birds	53	79	100	53	18
Mammals	17	100	100	100	38
Reptiles & amphibians	62	100	100	100	77
All	43	89	100	76	35

¹Fish and wildlife habitats in western Oregon and Washington, E. Reade Brown (ed.), USDA For. Serv. Pacific Northwest Region, unpublished appendix.

Managed Forests

The estimated rotation age is 65-85 years for intensively managed commercial timber land on the Siuslaw National Forest; this rotation age is proposed for 77% of the land area. Extended rotation ages of about 300 years are planned for the remaining 23% of the land base; this includes the Rock Creek watershed. If the above situation develops on the Siuslaw National Forest, 20 bird

and 5 mammal species will be severely reduced or even locally extirpated because successional stages 4-6 will be mostly eliminated (fig. 4).

Salvage treatment reduced snag densities slightly when compared to control forests, but densities of snags in clearcut/narrow buffer and clearcut/no buffer treatments were greater than or equal to those in control forests (table 2). Log densities in sluiced channels were reduced 70-90% from control levels, but in the clearcut/no buffer treatment densities of logs were similar to control levels (table 2). Log densities on toeslopes were reduced by salvage but log densities in clearcuts exceeded control levels (table 2).

Table 2.--Densities of snags and down logs after logging treatments, old-growth riparian zone forests, western Oregon.

Logging treatment	Down logs (ha ⁻¹)			Snags (ha ⁻¹)
	Channel/floodplain	Toeslope	Total	
	X(SE/N)			X(SE/N)
None (old growth)	584(117/7) ¹	291(89/2)	326	12(3/5) ²
Toeslope salvaged/channel sluiced	189(-/1)	177(-/1)	180	7(-/1)
Toeslope clearcut with narrow buffer strip/channel sluiced	55(-/1)	444(-/1)	373	29(-/1)
Toeslope clearcut with no buffer strip	602(168/5) ¹	878(-/1)	859	14(-/1)

¹This study plus Lammell (1972).

²This study plus Cline (1977).

Size reduction of woody debris habitat was an obvious alteration induced by logging. Compared to control forests average snag dbh and height decreased 48-76% and 62-90%, respectively, depending upon treatment; the same treatments reduced mean log diameter and length 9-38% and 24-59%, respectively (table 3).

The frequency distribution of snag decay stages was significantly different in old-growth riparian zone forests than in upland clearcuts (table 4). We made this comparison because we did not measure enough snags (n = 11) in clearcut riparian forests to compare statistically with snags in control forests. The decay stage distribution of logs was significantly different in

Table 3.--Dimensions of snags and down logs after logging treatments, old-growth riparian zone forests, western Oregon. Logs were decay stage 3 only.

Logging treatment	Snags		Logs	
	Diameter	Height	Diameter	Length
	(cm) X(SE/N)	(m) X(SE/N)	(cm) X(SE/N)	(m) X(SE/N)
None (old growth)	90 (3/144) ¹	19.9 (1.3/144) ¹	55 (4/67)	7.4 (1.3/67)
Toeslope salvaged/channel sluiced	22 (8/2)	7.3 (2.3/2)	50 (5/27)	5.6 (1.1/27)
Toeslope clearcut with narrow buffer strip/channel sluiced	39 (8/7)	7.5 (1.2/7)	44 (4/51)	4.1 (0.6/51)
Toeslope clearcut with no buffer strip	47 (5/4)	1.9 (0.3/4)	34 (1/108)	3.0 (0.3/108)

¹This study plus Cline (1977).

Table 4. Frequency distribution of wood decay stages after logging treatments, old-growth riparian zone and upland forests, western Oregon.

Logging treatment	Distribution by decay class, %				
	1	2	3	4	5
(a) Snags					
None (riparian old-growth) ^{a1,2}	2	19	36	11	32
Upland clearcut ^{b1}	18	39	23	4	16
(b) Logs					
None (old-growth) ^{a3}	0	2	68	26	4
Toeslope clearcut with narrow buffer strip and sluiced channel ^b	3	26	64	7	0
Toeslope clearcut with no buffer strip ^b	0	40	52	7	1

¹Cline (1977).

²For snags and logs, treatments with different letters are significantly different, chi-square test, $P < 0.005$.

³Includes toeslope salvaged/channel sluiced.

control forests than in both the clearcut/narrow buffer and clearcut/no buffer treatments (table 4). Salvage logging did not change the decay stage distribution of logs relative to control forests and was averaged with the control forests. Snags and logs were effected similarly by clearcutting: the frequency of decay stages 1 and 2 increased while the frequency of 4 and 5 decreased.

If the alterations of woody debris as described above are or will be widespread, then breeding habitat of the pileated and Lewis' woodpecker, and possibly the hairy woodpecker and common flicker will be reduced because the residual snags in clearcuts are near or below the minimum size used⁵ (Mannan et al. 1980). Harris et al. (1982) estimated a 10 and 29% decline in species in short rotation forests without snags and without snags and down logs, respectively. In contrast, we currently do not know the relationship between down log size and use by log-dependent mammals, reptiles, and amphibians.

Riparian Zone Buffer Strips

Wildlife biologists on the Siuslaw National Forest suggest areas adjacent to or within 100 m of water, i.e., riparian zones, as one of four locations for dead tree wildlife habitat⁶. The importance of riparian zones in providing dead tree habitat is explicit in these guidelines because riparian zones support diverse wildlife (Thomas et al. 1979) and minimize the direct conflicts with logging systems, herbicide application, slash burning and safety requirements. Toews and Moore (1982) recommend maintaining mature and old-growth forest buffer strips as a future source of large debris for streams. Are riparian zone buffer strips the panacea for dead tree management?

To examine this question we developed a hypothetical 100-ha snag management area within the South Fork of Rock Creek watershed. We subdivided the area using current information on the distribution of forest successional stages: 2.3, 8.2, 27.3, 50.4, 10.3 and 1.5 ha for successional stages 1-6, respectively⁷. The density and size distribution of snags was based on Cline (1977). Snag requirements of primary hole-nesting birds was calculated according to Thomas et al. (1979), except that we used a ratio of 31:1 for snags without to snags with cavities⁵.

⁵Manuwal, D. A. and J. Zarnowitz. 1981. Cavity nesting birds of the Olympic National Forest, Washington. College of Forest Resources, Univ. of Washington, Seattle. Unpublished manuscript. 143 p.

⁶Janik, P. and G. Silovsky [n.d.] Wildlife plan for dead and defective tree habitat. USDA Forest Service. Pacific Northwest Region. On file at the Siuslaw National Forest, Corvallis, Ore. 28 p.

⁷Stream Assessment Surveys. 1979-81. USDA Forest Service. Pacific Northwest Region. Siuslaw National Forest. Alsea Ranger District.

We estimated that the hard snag requirements of the six primary hole-nesting birds at the 100% population level would be met with 18% of all snags on the 100-ha management unit (Table 5). Riparian zone forests supplied a maximum of 35% of the total hard snag requirement, but 80% of these are < 30 cm dbh. If the riparian zone buffer strip was mature and old-growth only, a larger proportion of hard snags > 60 cm were supplied, but the total contribution to snag numbers decreased to 10%.

Table 5.--Snag resource and hard snag requirements of primary hole-nesting birds in riparian and hillslope forests on a hypothetical 100-ha snag management area, Oregon Coast Range.

Forest	Area ha	Number of snags			Total
		< 30 cm	30-60 cm	> 60 cm	
Riparian ¹	15	404	62	27	493
Hillslope ¹	85	5283	1086	845	7214
Total	100	5687	1148	872	7707
Hard snags required by wood- peckers, 100% population level ²		590	394	498	1408
% of snag requirement fulfilled by ripar- ian		68	16	5	
% of snag requirement fulfilled by ripar- ian, mature and old growth forests only		< 1	13	17	

¹See text for percent areas of each successional stage.

²Common flicker (*Colaptes aratus*), Pileated woodpecker (*Dryocopus pileatus*), Lewis' woodpecker (*Asyndesmus lewis*), yellow-bellied sapsucker (*Sphyrapicus varius*), hairy woodpecker (*Dendrocopos villosus*), and downy woodpecker (*Dendrocopos albolarvatus*).

Even if riparian zone buffer strips supplied all of the snags required for a 100-ha snag management area, they probably would be too small to meet the territorial needs of woodpeckers, most of which range > 10 ha⁸. In addition, most buffer

⁸Bruce Marcot. 1983. Personal conversation. Research Assistant, Department of Fisheries and Wildlife, Oregon State University, Corvallis, Ore.

strips, as currently designed, would not serve as a long-term source of woody debris habitat because they are too susceptible to uprooting by wind (Steinblums 1978). Among 27 buffer strips established 1-15 years ago in the western Oregon Cascades, the mean rate of uprooting was 33.3, 2.8, and 0.3 stem ha⁻¹ year⁻¹ for unstable, moderately stable and stable buffer strips, respectively. Assuming that these blowdown rates remained constant, we estimated their mean longevity to be 7, 36 and 151 years, respectively. Since uprooting rates probably slow down, these represented worst case estimates. We estimated that 67% of these buffer strips will stand less than 60 years. Stable buffer strips were protected from prevailing winds by high, nearby ridges and by surrounding, intact forest (Steinblums 1978).

We concluded that riparian zone buffer strips can only supplement the overall hard snag requirement of woodpeckers; upland forests will contain nearly two-thirds of all snags required at the 100% population level. However, buffer strips might be the best place to leave the largest snags and logs. Here they avoid direct conflict with logging while forming long-lasting habitat for both terrestrial and aquatic organisms.

SUMMARY

After logging old-growth riparian zone forests the average size of snags and logs decreased and the frequency of sound and slightly decayed wood increased relative to wood with advanced decay. Debris-dependent birds were estimated to be the most vulnerable to timber management because: (1) most birds were snag-dependent and after logging snags were too small for maximum species utilization, and (2) rotation lengths, especially future ones, will eliminate successional stage 4-6, where the number of bird species was highest. The woody debris resource of riparian zone forests can be used to supplement, but cannot replace, an active program of dead tree management in upland forests. Buffer strips as currently designed cannot be considered a long-term source of old-growth forest habitat or dead tree wildlife habitat, but the research of Steinblum (1978) suggests many ways to increase buffer strip stability. In addition, riparian zone buffer strips continue to perform other functions such as shading, litter deposition, and sediment and debris trapping as they stabilize.

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The Long-Term Effect of Timber Stand Improvement on Snag and Cavity Densities in the Central Appalachians¹

John J. Moriarty and William C. McComb²

Abstract.--Snag and cavity densities were measured on two watersheds in a mixed mesophytic forest in eastern Kentucky. One watershed received timber stand improvement (TSI) by girdling 20-30 years prior to measurement and one did not receive TSI. There were more snags on the TSI watershed than on the non-TSI watershed. Total cavity density was similar between watersheds, but the TSI watershed had a higher density of animal cavities while the non-TSI watershed had a higher natural cavity density. Management recommendations include selected TSI of heart-rotted trees on 10- to 15-year intervals to provide snags.

INTRODUCTION

The effects of tree girdling as a silvicultural method of timber stand improvement (TSI) on change in vegetation and wildlife habitat have been well studied (Murphy and Ehrenreich 1965, Metzger and Schultz 1981), but most studies have been short-term. There is a dearth of information on the long-term effects of tree girdling on wildlife habitat, especially on snag and cavity densities. Need for this information in the central Appalachians is increasing due to growing use of intensive forest management practices and loss of forest habitat through surface mining for coal.

Recommendations for management of snag-dependent wildlife species include long rotations of forest stands, retaining snags during harvest, injecting trees with a heart-rot fungus, and providing herbicide-killed trees (McClelland and Frissell 1975, Hardin and Evans 1977, Jackson et al. 1976, Conner 1978, and Evans and Conner 1979). Conner et al. (1981) and McComb and Rumsey (1983) reported the potential value of herbicide-killed trees for woodpeckers' habitat: spraying and injection of herbicides did not appear to adversely affect the tree

as a foraging or nesting site. Girdling of trees may provide foraging or nesting substrate for some species or may adversely affect cavity-dependent wildlife by killing cull trees with natural cavities (Miller and Miller 1980). Hence, this practice may actually limit the number of cavities available to species of cavity-dependent wildlife that require cavities in living trees. Girdling may result in snag characteristics different from those of natural snags, because of the rate and type of fungal decay in the tree (Conner et al. 1981). Normally, girdled trees do not remain standing as long as a natural cavity-tree or snag would stand (Miller and Miller 1980).

This study was undertaken to provide information on snag and cavity densities in TSI and non-TSI stands in a mixed mesophytic forest. The objectives were to quantify the long-term effects of girdling trees on snag and cavity densities and to determine the density of potentially usable snags and cavities per tree species.

STUDY AREA

The study was established in 2 watersheds on the University of Kentucky's Robinson Forest, located in Breathitt, Perry, and Knott Counties, Kentucky. Robinson Forest is a mixed mesophytic forest in the Cumberland Plateau region of Kentucky (Braun 1950). Xeric sites are dominated by scarlet oak (*Quercus coccinea*), black oak (*Quercus velutina*), chestnut oak (*Quercus prinus*), white oak (*Quercus alba*), red maple (*Acer rubrum*) and sourwood (*Oxydendrum arboreum*). Mesic sites are dominated by eastern hemlock (*Tsuga canadensis*), American beech (*Fagus grandifolia*), northern red oak (*Quercus rubra*) and yellow-poplar (*Liriodendron tulipifera*). It is a second-growth forest which was heavily cut prior to 1920. Davenport (1958) reported that extensive TSI, including the girdling

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²John J. Moriarty is presently stewardship biologist for the Kentucky Chapter of the Nature Conservancy, Lexington, Kentucky; William C. McComb is assistant professor of forestry and wildlife management at the University of Kentucky, Lexington, Kentucky.

of residual trees, was done from 1955-1960 on an area of the forest which included Falling Rock watershed (TSI treatment in this study) but not Bucklick Hollow (control in this study). Both watersheds encompass a drainage of approximately 80 ha and the altitude is from 300-412 m. Slopes are steep (20 to 100 percent) and characterized by short intermittent streams (Carpenter and Rumsey 1976).

METHODS

Study Design

Two 20-ha study areas were established, one in the Bucklick (control) watershed and the other in the Falling Rock (TSI) watershed. Each study area consisted of about 50 percent north slopes and 50 percent south slopes. A 50-point grid was established on an 80 x 50 m spacing and a 0.05-ha circular plot was established at each point.

Girdled trees, snags, and cavities were counted on each plot during the winter so that foliage would not obscure any cavity entrances. Cavity-trees and snags were identified to species whenever possible.

Vegetation over 10 cm dbh was tallied on each plot by species and diameter was measured to the nearest 0.1 cm. Basal area and density of each species were summed by plot. Relative dominance was calculated for each species on each watershed. Student's t-test was used to compare stand structural characteristics between watersheds. Linear correlation was used to investigate associations between various combinations of structural attributes on the study areas.

RESULTS AND DISCUSSION

Overstory

There were more trees ($P < 0.05$) on Falling Rock (TSI) (958 stems/ha) than Bucklick (non-TSI) (563 stems/ha). This was reflected in a higher average basal area estimate on Falling Rock (46.1 m²/ha) than on Bucklick (34.2 m²/ha). Differences between watersheds were probably due to the TSI practices on Falling Rock in the 1950's. There were more trees greater than 20 cm on Bucklick than on Falling Rock (fig. 1). Release of suppressed individuals following TSI allowed increased growth and higher stand density.

Tree species composition was similar between watersheds. There were 33 species on the Falling Rock watershed and 32 species on the Bucklick watershed; 30 species were common to both areas.

Snag and Cavity Densities

We found no girdled trees on Bucklick, but an average of 8.4 girdled trees per ha remained standing on Falling Rock (table 1). Snags were more evenly distributed among diameter classes on Falling Rock than on Bucklick (fig. 2). The density

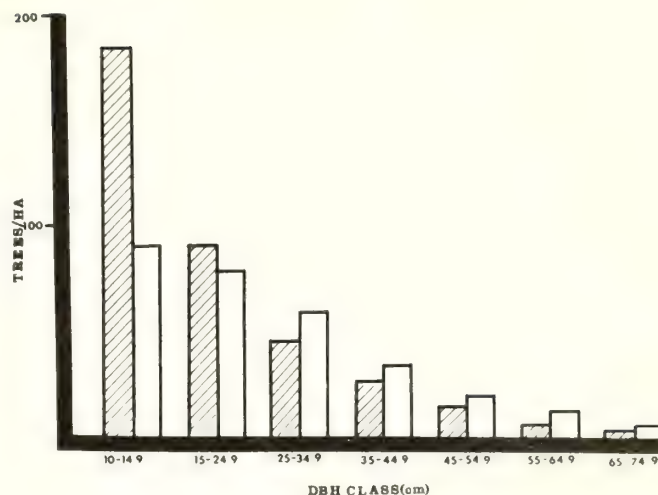


Figure 1.--Tree distribution by diameter class on TSI'd (cross-hatched) and non-TSI'd (open bars) watersheds, Breathitt County, Kentucky 1981, 20 years post-treatment.

Table 1.--Cavity and snag densities per hectare for two watersheds in Robinson Forest, Breathitt County, Kentucky, 1981.

Cavity Type	Watershed			
	Falling Rock (N=50) (TSI)		Bucklick (N=50) (Control)	
	Mean	S.E.	Mean	S.E.
Cavities				
Animal	15.6	0.51 *	10.4	0.46
Natural	6.0	0.34 *	12.8	0.39
Basal	8.8	0.34 *	7.2	0.30
Total	30.4	1.19	30.4	1.15
Snags	18.0	0.41 *	14.8	0.40
Girdled ¹	8.4	0.37 *	0.0	0

* $P < 0.01$

¹ Included within snag densities; 20 years post-treatment.

of girdled trees on Falling Rock was correlated with natural snag density ($r = +0.55$, $P < 0.01$) and total snag density (girdled trees and snags) was weakly correlated with the number of animal cavities ($r = +0.27$, $P < 0.01$). Snags provide primary excavators a soft substrate to excavate for nesting, and they provide a foraging substrate. Additional foraging substrate was available on Falling Rock in the form of snags 2.5 to 10 cm dbh. More of these small snags were found on Falling Rock ($\bar{X} = 46.4$ stems/ha) than on Bucklick ($\bar{X} = 20.4$ stems/ha) probably as a result of natural mortality in the TSI released stems. Large residual girdled trees provided more potential nest sites and feeding substrate for large cavity-nesters, such as pileated woodpeckers (*Dryocopus pileatus*), without adversely affecting availability of nest sites for small cavity-nesters (fig. 2). It should be noted however, that not all of the nest sites available would meet the requirements of large primary cavity-nesters due to a

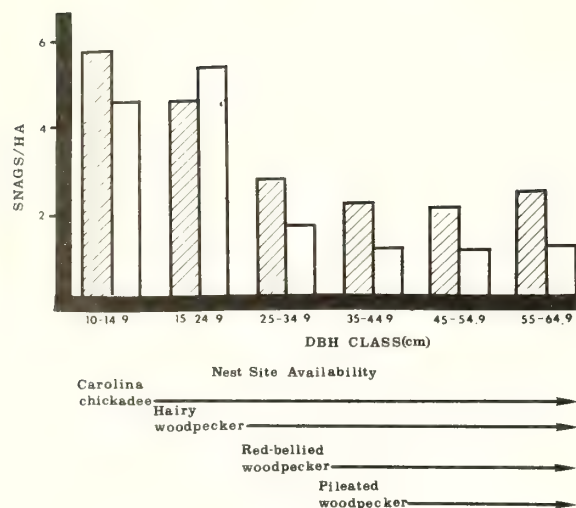


Figure 2.--Distribution of snags by diameter class on TSI'd (cross-hatched) and non-TSI'd (open bars) watersheds, Breathitt County, Kentucky, 1981, 20 years post-treatment. Nest site availability is also depicted for four common primary cavity-nesters.

spongy outer layer of the girdled snag. Pileated woodpecker nest holes were observed in several residual girdled trees on Falling Rock. Girdled trees infected with heart-rot prior to girdling may provide suitable nest sites.

There were more natural snags (3/ha) in northern red oak than in any other species (table 2). The highest density of girdled trees was found in American Beech; 83 percent of the beech snags had been girdled. Scarlet oaks and chestnut oaks were also girdled as cull trees on Falling Rock. Gustafson (1946) reported that red maple and American beech were not normally cut during the logging of the early 1900's and residual stems were heavily scarred by poor logging practices.

Standing snags in 1981 may have been different from what was created in the late 1950's because different species have different decay rates (Harmon 1982). Oaks are fast decayers ($\bar{X}=10\%/yr$), while sourwood and pines (*Pinus* spp.) are slow decayers ($\bar{X}=3.8\%/yr$) (Harmon 1982). The slow-decaying species favor the development of a greater number of animal cavities than fast-decaying species because they remain standing longer (Thomas 1979). Thin-barked, noncommercial species such as American beech, red maple, and sourwood, tended to have more natural

Table 2.--The density/10 ha of snags and cavities by tree species for two watersheds in Robinson Forest, Breathitt County, Kentucky, 1981.¹

Tree Species	Snags		Cavities						Total	
	TSI	Non-TSI	Animal		Natural		Basal		TSI	Non-TSI
			TSI	Non-TSI	TSI	Non-TSI	TSI	Non-TSI		
American beech (<i>Fagus grandifolia</i>)	48(40) ²	0	44(36)	0	8(8)	40	52(20)	16	104(64)	76
sourwood (<i>Oxydendrum arboreum</i>)	4	8	0	0	16	32	8	24	24(0)	76
unknown ³	16(4)	20	20(12)	40	4(4)	0	4(4)	0	28(20)	40
red maple (<i>Acer rubrum</i>)	0	0	32	0	4	4	4	12	40(0)	16
white oak (<i>Quercus alba</i>)	12(4)	8	12(4)	8	12	0	0	0	24(4)	8
blackgum (<i>Nyssa sylvatica</i>)	4	0	12	0	0	8	4	4	16(0)	12
scarlet oak (<i>Quercus coccinea</i>)	20(12)	8	0	4	4	8	4	4	8(0)	16
yellow-poplar (<i>Liriodendron tulipifera</i>)	12	4	8	4	0	4	8	0	16(0)	8
black oak (<i>Quercus velutina</i>)	12	8	4	16	0	0	0	0	4(0)	16
northern red oak (<i>Quercus rubra</i>)	16	12	0	12	0	4	0	0	0(0)	16
chestnut oak (<i>Quercus prinus</i>)	8(4)	12	4(4)	0	0	4	4(4)	0	12(12)	0
post oak (<i>Quercus stellata</i>)	0	4	0	0	0	8	0	8	0	16
others ⁴	28(12)	64	16	20	8	20	0	4	24(0)	44
TOTAL	176(76)	148	140(60)	104	56(12)	132	88(28)	72	300(100)	308

¹Data presented are based on 50 0.05-ha samples per watershed.

²Total with value for girdled trees that remained standing after 30 years indicated parenthetically.

³Snags that could not be identified to genus.

⁴Taxa with <2 cavities per 2.5 ha: *Betula lenta*, *Carya glabra*, *Carya* spp., *Cornus florida*, *Magnolia tripetala*, *Pinus* spp., *Quercus* spp., *Robinia pseudoacacia*, *Tilia* spp. and *Ulmus rubra*.

and basal cavities (table 2) caused by logging and fire injuries, which allow decaying agents to enter the tree and form cavities.

Density of snags >10 cm (including girdled trees) was significantly higher ($P < 0.05$) on Falling Rock (18.0 snags/ha) than on Bucklick (14.8 snags/ha) (table 1). These densities are lower than the densities found by McComb and Muller (1983) for a 30-year-old second-growth forest (85.6 snags/ha) in southeastern Kentucky. A managed forest in Connecticut had a density of 14.8 snags/ha (McComb and Noble 1980). McComb and Muller (1983) found a density of 44.2 snags/ha for an old-growth forest in southeastern Kentucky. The variation in snag densities between old-growth and second-growth forests can be explained by stand histories. The high snag density reported by McComb and Muller (1983) may be due to rapid regrowth with minimal site disturbance after cutting and subsequently greater annual mortality in the 30-year-old stand than in uncut stands. Robinson Forest was subjected to frequent fires immediately following cutting, and this disturbance probably resulted in slow regrowth and low annual mortality after 50 years.

Total cavity density for Falling Rock and Bucklick averaged 30.4 cavities/ha, but types of cavities differed between watersheds (table 1). Falling Rock had more ($P < 0.05$) animal cavities (15.6/ha) than Bucklick (10.4/ha) possibly because snags were more abundant on Falling Rock than Bucklick. Carolina chickadees (*Parus carolinensis*) frequently used the soft, remaining girdled snags but cavities created by chickadees may not be used by many other cavity-nesting species because of the small cavity size (Thomas 1979). Natural cavities were significantly ($P < 0.01$) more abundant on Bucklick (12.8/ha) than Falling Rock (6.0/ha). The girdling of the large hollow trees would accelerate falling due to lack of internal support. McComb and Rumsey (1983) reported similar reduction in natural cavity density following forest herbicide application at Robinson Forest. The recommended cavity density for maintaining viable populations of cavity-dependent species in the oak-hickory forest is 10 cavities/ha (Hardin and Evans 1977); lower than the cavity densities found on Falling Rock and Bucklick. Cavity densities on Falling Rock or Bucklick were higher than reported in other studies (McComb and Noble 1980, Carey and Healy 1981), but this may be due to differences in species composition, logging practices, or climatic conditions, all of which affect the suitability of a tree or snag for cavity formation.

MANAGEMENT IMPLICATIONS

Timber stand improvement by girdling provided additional feeding substrate and some nesting sites for primary cavity-nesters 20-30 years after treatment. Tree girdling reduced natural cavity abundance but increased animal cavity density. Secondary cavity users, such as barred owls (*Strix varia*), Virginia opossums (*Didelphis virginiana*), and gray squirrels (*Sciurus carolinensis*), which prefer natural tree cavities to animal-made cavities, may not benefit from TSI unless provisions are made to leave an adequate number of natural-cavity trees for these species.

Girdling of trees, particularly those which contain heart-rot, would be of benefit to some primary cavity-nesters and secondary cavity-nesters that prefer animal cavities. Release of suppressed trees by girdling large (>40 cm dbh) unmerchantable trees, particularly those with heart-rot, results in additional potential nesting sites for primary nesters, and long-term availability of feeding substrate due to natural mortality in the released trees. To supply a sustained yield of snags for cavity-nesters in 50-year-old second-growth central Appalachian stands we suggest girdling 1 or 2 heart-rot infected trees > 40 cm dbh per hectare on 10- to 15-year intervals. Natural mortality of TSI released stems will provide small and medium sized snags. At least 2 large, natural cavity-bearing trees per hectare should be left untouched to provide nesting sites for species preferring natural tree cavities. In the long run, this should provide a more equitable distribution of small, medium, and large diameter snags while still maintaining natural cavity density.

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The Effect of Firewood Removal on Breeding Bird Populations in a Northern Oak Forest¹

John V. Dingledine and Jonathan B. Haufler³

Abstract.--Breeding bird populations and snags were examined in relation to a controlled firewood removal in a northern oak forest in Michigan. Snag densities were significantly decreased by the firewood removal, but a complete reduction did not occur due to new snag generation and the presence of certain snags unsuitable as firewood. Cavity-nesting bird species were not decreased by the firewood removal due in part to the utilization of live trees or dead portions of live trees as nest sites. Snags did provide important foraging sites, but their loss did not cause identifiable decreases in the use of the study areas in this investigation.

INTRODUCTION

Past reductions in fossil fuels have led to a greater use of alternate energy sources. Wood, as a home heating fuel, continues to increase in popularity. For example, the number of firewood cutting permits issued by the White Cloud Ranger District of the Manistee National Forest has risen 414% between 1978 and 1982. Increasing demand for firewood poses a potential threat to the wildlife that utilize snags for food or cover. Many species of birds have been shown to use snags for numerous purposes including nesting, roosting, perching, and storing food (Thomas et. al. 1979, Miller and Miller 1980). The role of snags as nesting and foraging sites for the cavity-nesting bird species has been the subject of a number of recent studies (Conner et. al. 1975, Scott 1978, Conner 1980, Mannon, Meslow, and Wright 1980). Nest sites are generally considered a primary limiting factor in determining densities of these species. This study examined the impact of firewood removal on breeding bird populations and

habitat, especially snag densities and characteristics, within a northern oak forest in Michigan.

SITE DESCRIPTION

Six, 15 ha rectangular study plots were established within the White Cloud Ranger District of the Huron-Manistee National Forest, 12 km west of Big Rapids, Michigan. Plot boundaries were designated to make all plots as uniform in stand characteristics as possible. The distance between plots ranged from 200 m to over 1 km. Stands, consisting mainly of mature red oak (*Quercus rubra*) and white oak (*Q. alba*) along with smaller percentages of red maple (*Acer rubrum*), black oak (*Q. velutina*), and big-toothed aspen (*Populus grandidentata*), covered the study area. Midstory vegetation was comprised of witchhazel (*Hamamelis virginiana*), serviceberry (*Amelanchier* spp.), and sassafras (*Sassafras varifolium*).

Extensive vegetative sampling was conducted on each plot to quantify characteristics such as stem densities and vegetative cover. The absolute density of woody species >5 cm d.b.h. averaged 528 ± 73 per ha, with a mean basal area of 25.5 ± 3.5 m² per ha. Importance values based on relative density, relative frequency, and relative dominance averaged 102 ± 3.4 for white oak, 84.7 ± 10.5 for red oak, 57.8 ± 10.7 for red maple, 28.9 ± 4.1 for black oak, and 13.8 ± 4.9 for big-toothed aspen. The % vegetation cover measured in three height strata (<1 m, 1-7 m, >7 m) was used to calculate foliage height diversity (McArthur and McArthur 1961) which averaged 0.87 ± 0.02 . The average age of the stands was 65 years.

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³John V. Dingledine is a graduate assistant in wildlife ecology and Jonathan B. Haufler is a assistant professor of wildlife ecology, Michigan State University, East Lansing, MI.

METHODS

Three of the 6 study plots were randomly selected for treatment while the other three served as controls. In this study, treatment consisted of the removal of all dead standing or dead and down wood as per National Forest Service policy regarding firewood removal. In September 1981, the center 8 ha of each treatment plot was cleared of all firewood. A small number of the more rotten snags were considered unsuitable as firewood and were not removed to simulate conditions found on areas open to the public for firewood cutting. The uncut 50 m border zone served as a buffer and made it possible to examine any changes in bird distributions such as possible clumping of territories around the treatment area.

Breeding bird population densities were determined by the spot-mapping method following I.B.C.C. recommendations (1970). Birds were censused once before firewood removal in the breeding season of 1981 and once again following treatment during the 1982 season. At least 8 surveys were made of each plot each year between 10 May and 23 June. Census takers and their routes over the plots were regularly varied to control observer bias and compensate for changes in bird detectability with time of day. Following the censusing each morning, cavity-nesting birds were located and followed to determine active nest sites.

A survey of all snags >18 cm d.b.h. was conducted both years to determine snag densities and characteristics. Each snag in this size class was examined and the features of tree species, d.b.h., height, % bark cover, top condition, and number of branches were recorded. The presence of woodpecker foraging evidence and cavities was also noted.

These features were used to categorize snags into five different stages. These stages ranged from snags with 100% bark cover, intact top, and many branches to snags with 0-5% bark cover, broken tops and no branches (Fig. 1).

The density of snags in the 5-18 cm d.b.h. size class was determined by a random sampling method using 50 m x 50 m quadrats. Physical characteristics of snags in this size class were not recorded. Bird population parameters and snag densities were tested for significant differences by the use of t-tests.

RESULTS

A total of 915 snags >18 cm d.b.h. were surveyed in 1981 at a mean density of $10.2 \pm .89$ snags per ha. The density of snags in the 5-18 cm d.b.h. size class averaged 45.4 ± 5.9 per ha. The average d.b.h. of the snags in the larger size class was 24.6 ± 0.64 cm and ranged up to 50 cm. Woodpecker foraging evidence appeared on $44.6 \pm 2.1\%$ of the larger snags and more specifically on $74.5 \pm 2.8\%$ of the aspen snags. Only $8.8 \pm 1.9\%$ of the snags examined in 1981 held cavities. None of the above factors were significantly different between controls and treatments in 1981, prior to firewood removal.

The majority of the snags present on the study area in 1981 were in the early stages of snag succession (Fig. 2) based on the categorization scheme presented earlier. Few snags characterized by stage 5 were present. The % of snags with foraging evidence or cavities, however, was greater in the later stages (Fig. 3).

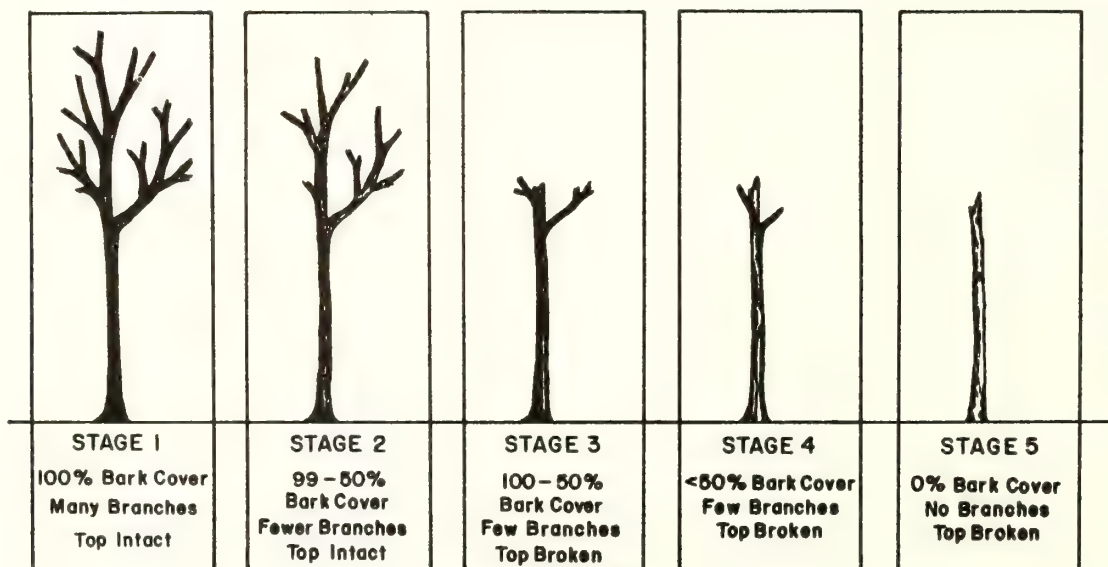


Figure 1. Description of the stages of snag decay based on physical characteristics of bark cover, top condition, and number of branches.

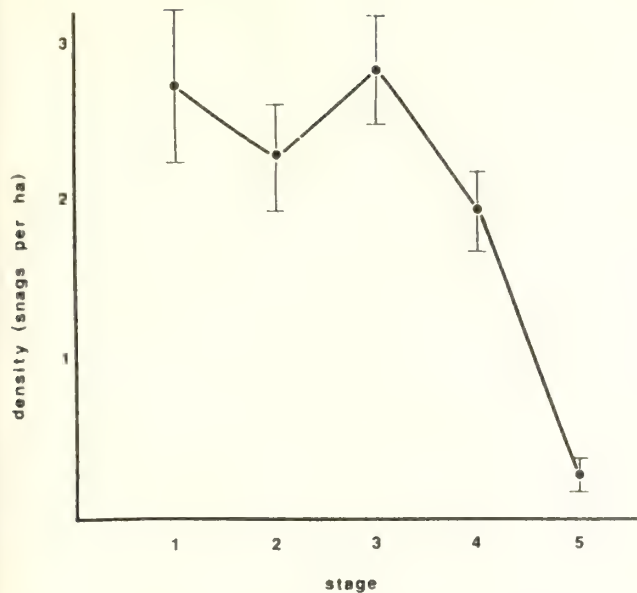


Figure 2.--Mean densities and standard errors of snags (>18 cm d.b.h.) by stage in 1981 in northern oak stands in Michigan.

Densities of snags (>18 cm d.b.h.) on treatment plots decreased significantly following firewood removal (Fig. 4). Snag densities over the entire treatment plot were reduced an average of $34.7 \pm 6.7\%$ while densities specifically within the treatment zone were decreased an average of $69.1 \pm 3.4\%$. Snags (5-18 cm d.b.h.) were also significantly decreased by firewood removal to $35 \pm 7.8\%$ of their original density of the entire plot. Total reductions in snag numbers were not achieved due the generation of new snags and the presence of a small number of snags that were unsuitable as firewood.

The aspect of snag generation was evident on control plots as well. All control plots showed a net increase in snag (>18 cm d.b.h.) densities with the exception of plot 5, where the net change in density was -0.37% due to the occurrence of some uncontrolled, non-project related firewood cutting. The average % change in snag densities on the other 2 control plots was $18.75 \pm 4.15\%$. Based on data collected on the two undisturbed control plots, live trees were becoming snags at a mean rate of 2.1 ± 0.6 per ha.

Fifteen species of breeding birds were included in the census of 1981 and 1982 (Table 1). The eastern wood pewee was the most abundant species followed by the red-eyed vireo. Six species of cavity-nesting birds were observed, but only three, the hairy woodpecker, the white-breasted nuthatch, and the great-crested flycatcher were found on all plots both years. Cavity-nesters made up 14.9% and 12.5% of the total population in 1981 and 1982, respectively. Prior to firewood removal, breeding bird populations averaged 189.5 ± 5.5 individuals per 40 ha and were not significantly different between control and treatment plots (Table 2). Following the treatment, bird populations on control plots were significantly

greater ($P < 0.10$) than those on treatment plots. These differences were due mainly to greater numbers of scarlet tanagers and ovenbirds. Densities of cavity-nesting birds on treatment plots were not significantly different from control plots either before or after firewood removal. Bird species richness and diversity were not affected by the treatment.

Nest sites of all cavity-nesting birds were not successfully located, but at least one nest site was located for each cavity-nesting species with the exception of the great-crested flycatcher (Table 3). Most nests found were those of the hairy woodpecker and the white-breasted nuthatch. The low number of nest sites located for the downy woodpecker, black-capped chickadee, and red-headed woodpecker corresponded to the infrequent occurrence of these species on the study plots. Oaks were selected the most frequently by all cavity-nesting species except for the hairy woodpecker which more often selected aspen. Eighty-six % of all nests were located in live trees or dead portions of live trees and only 14% of the nests were located in snags.

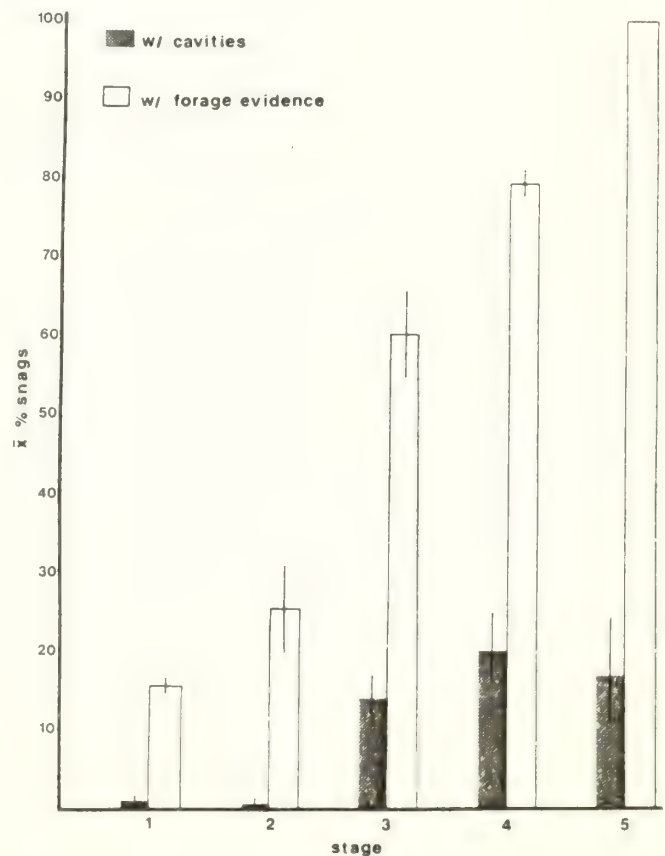
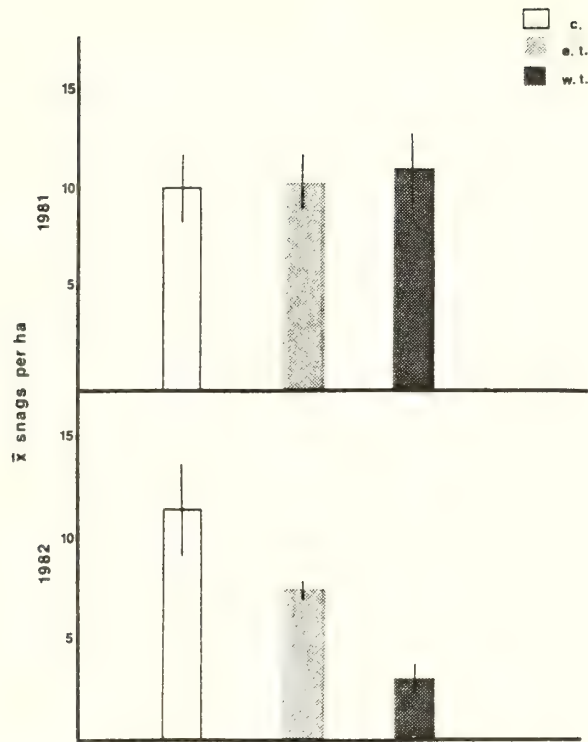


Figure 3.--Mean and standard error of snags (>18 cm d.b.h.) with foraging evidence and cavities in 1981 in oak stands in Michigan.

DISCUSSION

Results of the bird census and snag survey conducted in 1981 confirmed that control and treatment plots did not differ in terms of snag densities or bird populations prior to firewood removal. Vegetative sampling completed during the study period also showed no major differences in the plant community, so that the only significant difference in bird habitat between control and treatment plots in 1982 was the decrease in snag densities resulting from the firewood cutting. The significantly ($P < 0.10$) lower density of breeding birds on the treatment plots in 1982 is difficult to relate to the reduction in numbers of snags because the species accounting for most of the difference were not cavity-nesters.

The absence of an expected decrease in cavity-nesting bird species may have been due to several factors. First, most of the cavity-nesting birds inhabiting the study plots preferred to nest in live trees or dead portions of live trees. The preference for live trees exhibited by the hairy woodpecker and the white-breasted nuthatch has been noted by other authors (Kilhorn 1968, Lawrence 1966). The use of live aspen by hairy woodpeckers follows with the observations of Lawrence (1966) but is in contrast to those of Conner (1976). The lack of data collected for the great-crested flycatcher made it impossible to determine whether it was more often selecting cavities in live trees or snags, but regardless, detections of this species did not decrease after firewood removal. Secondly, snag densities present on the study plots before treatment were considerably above levels recommended by Evans and Conner (1979) for woodpecker species typical of this vegetation type, so that significant reductions in snag numbers may have still left enough remaining snags to support the populations. The average snag



*significantly different ($P < 0.02$) from controls.

Figure 4.--Mean snag (>18 cm d.b.h.) densities and standard errors for control plots (c.), entire treatment plots (e.t.), and within the treatment area (w.t.) before and after firewood removal in oak stands in Michigan.

Table 1.--Average numbers of breeding birds by species before and after firewood removal on 15 ha study plots in northern oak stands in Michigan.

Common name (Scientific name)	1981		1982	
	Control $\bar{X} \pm S.E.$	Treatment $\bar{X} \pm S.E.$	Control $\bar{X} \pm S.E.$	Treatment $\bar{X} \pm S.E.$
Red-headed woodpecker (<i>Melanerpes erythrocephalus</i>)	0.67±0.67	0.67±0.67	-	-
Hairy woodpecker (<i>Picoides villosus</i>)	3.3±0.67	2±0	2±0	2±0
Downy woodpecker (<i>Picoides pubescens</i>)	-	-	0.67±0.67	-
Great-crested flycatcher (<i>Myiarchus crinitus</i>)	2.6±0.67	2.6±0.67	2±0	2.6±0.67
Eastern wood pewee (<i>Contopus virens</i>)	18.7±0.67	18.7±1.7	16.7±2.9	16.7±1.3
Blue jay (<i>Cyanocitta cristata</i>)	1.3±0.67	4.6±0.67	6.7±0.67	4.6±1.3
Common crow (<i>Corvus brachyrhynchos</i>)	-	-	-	0.67±0.67
Black-capped chickadee (<i>Parus atricapillus</i>)	-	1.3±1.3	2±1.1	0.67±0.67
White-breasted nuthatch (<i>Sitta carolinensis</i>)	4±0	4±1.1	4±0	4±1.1
American robin (<i>Turdus migratorius</i>)	0.67±0.67	0.67±0.67	1.3±0.67	-
Yellow-throated vireo (<i>Vireo flavifrons</i>)	-	-	0.67±0.67	1.3±0.67
Red-eyed vireo (<i>Vireo olivaceus</i>)	15.3±0.67	10.7±2.4	16.7±1.3	14.6±1.3
Ovenbird (<i>Seiurus aurocapillus</i>)	9.3±1.8	10.7±1.8	12±1.1	8.7±3.3
Scarlet tanager (<i>Piranga olivacea</i>)	6.7±1.3	8±2.3	12±1.1	6.7±1.8
Rose-breasted grosbeak (<i>Pheucticus ludovicianus</i>)	8.7±1.8	8.7±1.8	10±2	11.3±1.8

Table 2.--Breeding bird community characteristics before and after firewood removal on study plots in northern oak stands in Michigan.

	1981		1982	
	Treatment	Control	Treatment	Control
	$\bar{X} \pm \text{S.E.}$	$\bar{X} \pm \text{S.E.}$	$\bar{X} \pm \text{S.E.}$	$\bar{X} \pm \text{S.E.}$
Bird density (40 ha)	194 $\pm$ 4.6	189 $\pm$ 6.3	196 $\pm$ 9.4*	230 $\pm$ 8.6*
C.N.B. density (40 ha)	28 $\pm$ 1.8	29 $\pm$ 1.8	25 $\pm$ 4.7	28 $\pm$ 3.5
Species richness	10 $\pm$ 0.6	9.7 $\pm$ 0.3	10 $\pm$ 0.0	10.7 $\pm$ 0.9
Species diversity ¹	2.04 $\pm$ 0.06	2.00 $\pm$ 0.05	2.07 $\pm$ 0.11	2.07 $\pm$ 0.08

*significantly different ($P < 0.10$)

¹) calculated by the Shannon Weaver Index

d.b.h. was also within the ranges used by woodpeckers with the exception of the pileated woodpecker (*Drycopus pileatus*), although this species was observed foraging on the plots occasionally.

The near total absence of the downy woodpecker may have been due to the high percentage of snags in the early stages of snag succession, which may have been too "hard" for this species to excavate (Conner 1978). The higher percentage of older snags having cavities points to the increasing value of a snag as it ages. Since firewood cutters normally prefer the harder snags in an early stage of snag decay, the impact of the removal on some species may become more pronounced with time when no new snags will be left to age.

The importance of snags as foraging sites was evident by the high number exhibiting signs of use. Aspen species, in particular, appeared important in this regard. Due to the poor quality of aspen as firewood, it is usually less often selected by firewood cutters, and was often the species of snag not cut in this study due to its rapid decay. However, as the stands investigated age, aspen will become less frequent due to successional change, and other species of snags, such as oaks, will become more important as foraging sites. Again, the high % of foraging evidence on snags in the later stages of decay may mean that the effect of firewood removal may become greater with time.

Table 3.--Condition of nest trees used by the cavity-nesting bird species in northern oak stands in Michigan.

	Live tree	Dead portion of live tree	Dead tree
Hairy woodpecker	4	0	0
White-breasted nuthatch	6	0	1
Downy woodpecker	0	1	0
Black-capped chickadee	1	0	0
Red-headed woodpecker	0	0	1

The generation of new snags was clearly evident on the control plots and is a factor which may reduce the impact of firewood removal. Although the trees that died and became snags between 1981 and 1982 were probably not very suitable for cavity-nesting species and also provided poor foraging sites, their value to cavity-nesters will increase in time if they are not removed by additional firewood cutting. However, it would take approximately four to five years for snag generation to produce recommended numbers of snags (Evans and Conner 1979) and many more years before these snags decayed to the preferred stages.

A final consideration in the results of the study related to the dimensions of the study plots. Although a 15 ha study plot size approached the limit of managability of the project, large numbers of cavity-nesters important in showing statistically significant changes did not occur in the study plots due to the large territory size of most cavity-nesting species.

MANAGEMENT IMPLICATIONS

Results of this study suggest that small areas within this vegetation type could be harvested for firewood without significant reductions in cavity-nesting bird populations due to the extensive use of live trees or dead portions of live trees for nesting by these species. This does not mean that the loss of snags over large areas would not decrease bird numbers, but that blocks up to 8 ha in size may be intensively harvested over a short time span. Cavity-nesting species in other vegetation types may show a different response if they are more dependent on snags, as has been suggested by other authors, than the species observed in this study. However, even in northern oak forests, continual harvesting of newly formed snags may be detrimental because eventually no snags in the later stages of decay will be present.

The importance of aspens as foraging sites as well as nesting sites in both live and dead trees indicates that at least small percentages of this or other "soft" species should be encouraged in forest stands. Timber harvesting and timber stand improvement practices might be modified to include such considerations.

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Management of Snags and Den Trees in Missouri — A Process¹

Russ Titus²

ABSTRACT.--The Missouri Department of Conservation and Mark Twain National Forest have been reviewing and refining standards and guides for managing wildlife habitat. An important part of this effort has been to more clearly define the biological basis for dens and snags and to develop management guidelines. A committee was assigned to review available literature on 89 species of birds, mammals, amphibians and reptiles known to require snags and/or den trees to meet their life history requisites in Missouri. Data on these species such as territory size, maximum populations/100 acres, and den tree characteristics such as diameter at breast height, cavity height, and number of dens per acre required for maximum populations were compiled. The species were then segregated by their use of broad habitat types which were identified as Forest Interior, Semi-open/Open Land, and Wooded Watercourses, referred to as Land Use Patterns (LUPS). Biological requirements were established for each major land use pattern and management techniques recommended for even-age and uneven-age silvicultural systems.

INTRODUCTION

Missouri is in the Middle Mississippi Valley. The land area is 69,674 square miles with 448 being water surface (Steyermark 1963). Elevations range from 230 feet in the southeast to over 1,700 feet in the Ozark Plateau.

Thom and Wilson (1980) classified six major natural divisions in Missouri based on geological history, soils, bedrock geology, topography, plant and animal distribution, presettlement vegetation and other factors. These divisions and man's influence depict the diversity of conditions in Missouri which influence the availability of snags³ and den trees⁴. These natural divisions represent 1) the influence of big

rivers which created lowland and riparian habitats; 2) the Ozark uplands which are a highly dissected peneplain, heavily forested with oak-hickory and oak-pine types and, 3) the plains of west and north Missouri, glaciated north of the Missouri River, and which once represented 18,474 square miles of tall grass prairie (Schroeder 1981).

Man's influence has greatly altered the forested portions of the prairie and the forested region itself. This activity has had an adverse impact on wildlife species requiring snags and den trees (McComb 1982). Once native to Missouri, the ivory-billed and red-cockaded woodpeckers are extinct or extirpated. These species succumbed to such activities as excessive forest type conversion, unregulated clear-cutting, tree-length skidding, high fuelwood utilization and removal of defective trees. These activities all influence the quality and quantity of snags and den trees.

Biologists in Missouri recently embarked on a joint effort between the Mark Twain National Forest and the Missouri Department of Conservation to review species requirements for snags and den trees, evaluate current management practices and their potential impacts on these species and to recommend management techniques compatible with a variety of management practices.

¹Paper presented at the snag habitat management symposium. (Northern Arizona University, Flagstaff, June 7-9, 1983).

²Russell Ray Titus is a Land Management Biologist for the Missouri Department of Conservation, Jefferson City, MO.

³A snag is defined as a dead tree at least six inches in diameter breast height (dbh) which is at least ten feet tall.

⁴A den tree is defined as a live tree with a cavity large enough to shelter wildlife.

BIOLOGICAL REQUIREMENTS

Procedure

A list of birds, mammals, reptiles and amphibians requiring snags and den trees was compiled showing that 89 species of wildlife in Missouri require these special habitat characteristics (Schwartz and Schwartz 1959, Conner and Adkisson 1974, Hardin and Evans 1977, Johnson 1977, Brawn 1979, Evans and Conner 1979, DeGraff et al. 1980). Habitat characteristics⁵ were compiled and tabled for all species.

The procedure used to define biological requirements was as follows:

1. The list of species was segregated by primary excavators or secondary cavity users.
2. Species were then organized by their preference for broad habitat types. Habitats were based on land use patterns (forest interior, open and semi-open lands, and wooded water courses) which are defined later in the text.
3. Species within land use patterns were further segregated by the size class of tree required to meet their needs. The size classes are greater than 19" dbh, 10-19" dbh and less than 10" dbh.
4. Data on species using each size class were analysed to determine the number of dens and/or snags required per acre. Territory size, maximum population per 100 acres, minimum dens or nest trees required per pair were some of the criteria used to obtain this quantity.
5. The number of snags and/or den trees required per acre for all species at high population levels were summed for each size class of den tree or snag for each land use pattern. Table 1 illustrates these results.

Forest Interior Habitats

Management recommendations for the forest interior land use pattern are based on the biological needs of eight primary excavators and 22 secondary cavity users. These species display a proclivity for contiguous forest cover but will probably exist at low population levels in parts of the state with little forest cover. Best opportunities to manage for these species at high population levels exist in the heavier

TABLE 1.--Optimum densities of snags and/or den trees per acre by three broad habitat types.

Diameter Class	Forest Interior		Semi-open And Open	Wooded Water-Courses
DBH(inches)	Dens	Snags	Dens ¹	Dens ¹
Greater Than 19"	1	0	3	2
10" - 19"	4	4	4	14
Less Than 10"	$\frac{2}{7}$	$\frac{2}{6}$	$\frac{3}{10}$	$\frac{9}{25}$

¹Animal needs are in den trees because snag creation by deadening trees is not generally recommended in these land use patterns.

forested areas. Objectives for snags and den trees are shown in Table 2.

TABLE 2.--Optimum snags and den trees required per acre by size class to attain high populations of all forest interior species and lower management levels.

<u>Diameter</u> <u>Class</u>	<u>Forest</u> <u>Interior</u>		<u>Percent of Optimum</u>				
<u>DBH (inches)</u>	<u>Snags</u> ¹	<u>Dens</u>	<u>90%</u>	<u>80%</u>	<u>70%</u>	<u>60%</u>	<u>50%</u>
Greater Than 19"	0	1	0.9	0.8	0.7	0.6	0.5
10" - 19"	4	4	3.6	3.2	2.8	2.4	2.0
Less Than 10"	2	2	1.8	1.6	1.4	1.2	1.0

¹Snag and den tree requirements are similar because many species would use either live or dead trees and the number of species requiring live den trees approximated the number of species requiring dead trees. Minimum was chosen as half of optimum management with intermediate levels displayed.

Although snag management was integrated with den tree management, it should be emphasized that trees are predominant in the forest interior, therefore, snag objectives should be relatively easy to achieve with the exception of larger diameter trees. Because snags are provided by natural or man induced mortality and do not need the protection den trees require, we can strive for more even distribution and the optimum level of management.

⁵This information is available from the author at Box 509, Rolla, Missouri 65401.

Management guidelines to achieve these goals are:

1. Manage for optimum snag objectives, but do not compromise den tree objectives.
2. Distribution of snags should be even across the landscape (Bull et al. 1980).
3. Management should favor tree species which are relatively rot resistant and long lived⁶.
4. Snag objectives for trees greater than 19" dbh should be met only if there are surplus trees in this diameter class.

Semi-open and Open Habitats

Four primary excavators and 21 secondary users show habitat preferences for snags and den trees in the semi-open and open land use patterns (Schwartz and Schwartz 1959, Conner and Adkisson 1974, Hardin and Evans 1977, Johnson 1977, Brawn 1979, Evans and Conner 1979, DeGraff et al 1980.) In this habitat trees may be more critical than in the forest interior.

DBH Class	Optimum No./Ac.
Greater than 19"	3
10" - 19"	4
Less than 10"	3

Most species did not show a preference for den trees or snags in this habitat type. Because live trees may be critical in these conditions, recommendations are that den tree management take precedence over snag management.

In the semi-open and open land patterns, the objectives for snags and den trees can only apply to those acres which can provide enough trees. If a stand has 10 or more trees per acre, it should qualify as having the potential to provide den trees through time.

Two conditions will exist which may influence the manager's objectives for snags and/or den trees. These are stands not productive for commercial timber (noncommercial forest lands) with site index less than 40, and stands of commercial timber (commercial forest land) with site index greater than 40.

When a stand is classified as noncommercial, and has less than 40 square feet of basal area in timber, the value of trees as dens or potential dens warrants management at or near the optimum level. If there is greater than 40 square feet basal area of trees, the optimum

level of management can be utilized; however, snag objectives may be met by induced mortality or by natural mortality. Snags on these lands should be selected from surplus stems above den tree objectives. Snag management should never compromise den tree objectives.

When stands are classified commercial forest land and are to be managed for forest products as well as wildlife habitat, the management level for den trees may be reduced below optimum, but should not be lower than 50% of optimum. Species selected for reserve den trees or potential den trees should be selected following guidelines that recommend ⁷long lived species which attain large diameters⁷.

When basal area exceeds 40 square feet and the decision is made to sacrifice living trees to provide snags, then protect the best den trees and deaden the residual. Spacing of snags should be distributed throughout each stand. (Bull et al. 1980).

Wooded Watercourses

Wooded watercourses are a scarce and disappearing habitat. They occur on alluvial flood plains and benches of streams which have very productive soils for timber as well as agricultural crops.

Wooded watercourses are the least predominant and the highest in quality when compared to other broad habitats. They provide critical habitat for eight of ten primary excavators found in Missouri. Twenty-seven secondary cavity users also utilize cavities in wooded watercourses, eight which find their life requisites only along wooded watercourses.

The species' requirements for snags and den trees in wooded watercourses did not vary greatly between wooded watercourses not within 200 feet of permanent water (lowland hardwoods) and wooded watercourses within 200 feet of permanent water (riparian). Riparian and flood plain hardwoods were separated from lowland hardwood primarily to facilitate multi-resource management. There was no evidence of a preference for snags over den trees, so requirements are given as den trees. These requirements are shown below:

DBH Class	Optimum Den Trees/Ac.	Minimum Recommended Dens/Ac.
Greater than 19"	2+	1
10" - 19"	14+	7
Less than 10"	9+	4

⁶Species information is available from the author at Box 509, Rolla, MO 65401.

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Snags in the riparian and flood plain hardwoods zones should be managed by natural mortality only. Because of the physiological characteristics of the tree species occurring there (softer wood and shorter life expectancy than upland hardwoods), snag requirements should not be a limiting factor.

DETERMINING OBJECTIVES

The biological requirements presented above provide the basis for establishing agency or landowner objectives. Other multi-resource objectives may require objectives below the optimum. Objectives can be established by:

1. Determining the appropriate set of guides from the land use pattern key.
2. The silvicultural system used.
3. The role of old growth.
4. The specific objectives in relationship to optimum.

Land Use Patterns

To determine appropriate species and biological standards it was necessary to define major land use patterns in Missouri. The committee identified three major patterns (forest interior, semi-open and open) based on habitat preferences of the species. Three additional combinations (forest inclusion in semi-open and open, and semi-open inclusion in forest interior) were also identified. Descriptions of these land use patterns are:

Forest Interior: Greater than 70% of a 5,000 acre evaluation area in contiguous forest cover. (fig.1)

Semi-open: 70-20% forested of a 5,000 acre evaluation area (fig. 2).

Open: Less than 20% forested. (fig.2).

Forest Interior Inclusion in Semi-open or Open Land Use Pattern: A block of contiguous forest cover qualifies to be managed for forest interior species in a semi-open or open land use pattern if it is at least 1,000 acres managed by an even-age system or 500 acres managed by an uneven-age system. (fig.2)

Semi-open Inclusion in Forest Interior Land Use Pattern: When 20% of relatively contiguous semi-openland exists in a forest interior land use pattern. (fig.1)



FIGURE 1.--Figure illustrates the forest interior land use pattern and an example of forest interior with a semi-open inclusion. Each illustration represents a 5,000 acre land area. Shaded areas are forest cover.

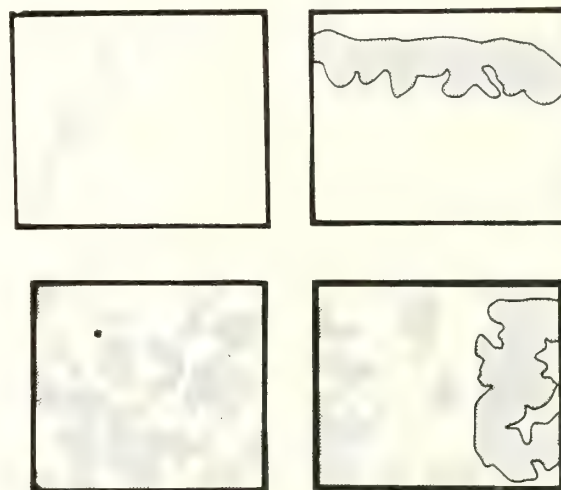


Figure 2.--Figure illustrates open land use pattern (top) and semi-open land use pattern (bottom) with examples of a forest interior inclusion. Each illustration represents a 5,000 acre land area. Shaded areas are forest cover.

Later in the process the committee decided that recommendations for semi-open and open land use patterns were so similar that they should be combined.

These land use patterns further help the land manager decide what species and guides should be emphasized by the use of a dichotomous key. This key was designed using the land use patterns and their combinations as well as the wooded watercourses which may occur within any land use pattern. This key should also standardize the interpretation of snag and den tree objectives as they are applied.

KEY TO GUIDES BY LAND USE PATTERNS

A. Forest Interior (Greater than 70% forested)	B
A. Semi-open (20 to 70% forested) and open lands (less than 20% forested)	F
A. Wooded Water Courses	I
B. Forest Interior with little or no semi-open and open lands)	C
B. Forest Interior with Semi-open and Open Lands clumped (500 ac. of semi-open and open in 25% of 5,000 ac.)	D
B. Forest Interior with Semi-open Stands	E
C. Apply Forest Interior Objectives	-
D. Apply Forest Interior Objectives to Forest Portion and Semi-open/Open Objectives to Semi-open/Open Portions	-
E. Apply Semi-open Land Objectives by Stands	-
F. Forested Portion Dispersed	G
F. Forested Portion Clumped	H
G. Apply Semi-open Land Objectives	-
H. 1,000 Ac. Forest Under EAM or 500 Ac. Under UAM or No Management. Apply Forest Interior Objective to the Forested Portion	-
I. Wooded Water Course not Within 200 feet of Permanent Water. Apply Lowland Hardwood Objectives	-
J. Wooded Water Course Within 200 feet of Permanent Water. Apply Riparian Objectives	K

Silviculture Systems

Major silviculture systems implemented in the United States are clear-cutting, seed-tree, shelterwood, single-tree selection, and group selection. Clear-cutting, seed-tree, and shelterwood systems generate stands of trees of the same age. This system is called even-age management (EAM). Single-tree selection and group selection produce and maintain stands of trees of several age groups. This system is called uneven-aged management (UAM) (Society of American Foresters with Cooperation of the Wildlife Society 1981). Both the even-age and uneven-age systems are used in Missouri, the size of ownership and landowner objectives will determine which system is most suitable. The system selected will influence the techniques and practices necessary to meet den tree and snag objectives (the number and size/acre).

Old Growth

Past land management on Missouri's public lands has attempted to accommodate the needs of

species requiring snags and den trees by designating 8-12% of each management unit as old growth or potential old growth. This paper illustrates that adequate numbers of dens and snags cannot be provided from a limited amount of old growth. Although the number of snags and dens within these stands are, or will be high, their existence is clumped on the landscape causing very dispersed distribution. Advantages of using old growth management are that these stands can be identified, designated, and protected from harvest, while the rest of a management unit may then be treated with little or no regard for snags and den tree management.

The amount and quality of old growth can make an important contribution to meeting den tree and snag objectives. However, the emphasis on old growth varies among landowners and agencies and old growth alone may not meet den tree and snag requirements.

MANAGEMENT TECHNIQUES

Management for snag and den tree objectives should be met over large (approximately 1,000 acres) areas. Opportunities to reach these objectives will vary greatly according to the characteristics of stands involved. Site potential, topography and especially dominant size class of the stands in the evaluation area will influence the manager's capability to achieve objectives. Administrative objectives will also influence the intensity of den tree and snag management. Because these variables exist we have suggested a variety of techniques and recommendations to assist managers with their objectives.

Achieving den tree objectives under present stand conditions in Missouri may be difficult. Limited inventories on lands managed by the Missouri Department of Conservation and the U.S.D.A. Forest Service show den tree densities presently range from one to eight per acre, usually three to five per acre. These are generally in the 10-19 inch DBH size class, the large den trees (greater than 19 inches dbh) are scarce. If the manager was to set top priority on cavity users, the optimum system would be not to cut any trees, but designate the tract as old growth for perpetuity. However, this is the exception rather than the rule as land managers attempt to manage under the multiple-use concept.

Even-age Management

There are three prescriptions common to even-age management, 1) clear-cut, 2) intermediate thinning; and 3) leave. To achieve den tree objectives for a tract of land the manager will need to meet objectives on a per acre average by stand. If the stand prescription is to leave or be designated as old growth then little concern should be given to the preservation of the den tree component. When treatments are prescribed, methods will vary with the type of treatment and stand age.

Clear-cut Prescription (Regeneration)

When a stand is clear-cut its contribution to den tree and snags will be negligible for at least 50 years unless trees are designated to remain. In the regeneration stands two techniques may be applied either singly or in combination; individual den trees may be left or the clump technique may be used. Either technique or combination may be utilized, but seldom can optimum objectives be achieved through time, primarily because there is limited knowledge of den tree survival or how many need to be left to meet objectives after natural mortality.

The manager should consider the clump technique when the aspect of a stand will expose leave trees to high winds. Generally, protected drainages, coves, and north and east slopes should be the best locations for both individual trees or clumps. Strive to leave trees with long life expectancies when the choice is available i.e., the white oak group should be selected over the black oak group.

Individual Tree Selection: Snag and den tree objectives can be met by selecting individual trees to reserve as den trees or to be deadened as snags. This technique can be utilized in all silvicultural management systems, but does have associated disadvantages as well as some definite advantages. Biological disadvantages associated with trees selected to remain in clear-cuts are:

1. Individual den trees grown in a forest stand have relatively small root systems which do not anchor the tree well enough when left in a new opening with associated high winds. These trees are vulnerable to windthrow.
2. Added stress of winds and lightning may cause breakage of tops and boles.
3. The drastic change of micro-climates can cause top dieback and tree mortality.

Some management disadvantages also present themselves:

1. Accounting for individual trees to ensure that objectives are being met poses some administrative difficulties, especially when several crews are marking reserve trees.
2. Protecting these reserve trees during post sale activities presents a problem i.e., cordwood and firewood operations, natural regeneration work and precommercial and commercial treatments of young stands.

Advantages of the single tree selection tend to be for the animal species rather than administrative. These advantages are:

1. An actual count can be made (either in regenerated stands or intermediate treat-

ments) which helps the manager know when his snag and den tree objectives are being met.

2. An even distribution of snags and den trees can be achieved because an attempt is being made to leave them as they occur on the landscape⁸. This may reduce intra- and inter-species competition for dens. (Bull et al. 1980)

When the individual tree selection method is used, select species with long life expectancies. These trees should be selected in protected locations when possible i.e., side slopes and drainages. When regenerations are located on the more exposed sites of the landscape, the manager may want to utilize the clump method of leaving reserve den trees.

The Clump Method: To ensure that den trees and large diameter snags are available in stands 10-50 years after a regeneration cut will require a different management technique. The manager can choose one or more large existing dens and reserve a portion of the stand surrounding them to protect them during the post clear cut stage. Some shortcomings are associated with this technique if used unilaterally to meet den tree objectives. The distribution of dens is not even on the landscape and meeting den tree objectives is difficult because den trees plus shelter trees take up a large amount of the area.

The committee elected to count shelter trees as potential den trees and snags. Advantages associated with this method are:

1. It would reduce or eliminate many of the stresses associated with isolated trees, providing for longer wildlife utilization.
2. Clumps can be excluded during sale layout and kept intact and trackable through successive treatments.
3. Trees left as protection for dens would provide a source of potential large dens and snags in young (10-50 year old) stands.

Based on stocking charts by Ashley (1980), the optimum⁷ live dens by recommended size classes, occupies 7% of each acre; however, it is more desirable to leave a clump large enough to be distinguishable during management activities and yet provide distribution on the landscape. The following selection and spacing criteria are based on ranges of pertinent wildlife species. For each five acres of opening the specified clump size is needed to meet den requirements. The clump should contain one or more larger (greater than 10 inches) dens per 1/3 acre of clump. As management intensity is decreased

⁸Den tree spacing guides are available from the author at Box 509, Rolla, MO 65401.

from optimum we recommend that the clump sizes be decreased, but the manager continue to maintain a clump per 5 acres of regeneration.

Den Management Level	Clump Size in Acres per 5 Acres of Regeneration
90-100%	1/3
70-90%	1/4
50-70%	1/5

The following criteria should be followed when selecting the location of clumps in clear-cut stands. They are ranked by priority.

1. Select trees with largest diameters that have obvious active dens and reserve 3-5 (dominant or codominant) trees around them, regardless of topography or proximity to stand boundaries.
2. Select areas to be reserved, such as finger draws that protrude into regeneration patches and sink hole inclusions. Reserve all den trees and surrounding trees within the draw or sink hole.
3. Select den trees and clumps of reserve trees near the lower end of the slope or just below the top of the ridge. Avoid reserving individual trees on mid-slopes or ridge tops.
4. In ridge top stands, reserve clumps of trees surrounding den trees near the edges of the stand.
5. If clumps are reserved in the center of regeneration patches, also reserve trees leading from the edge of the stand to the reserve clump or from a reserved clump in a draw to the center reserve clump.
6. Species of den trees selected are critical. If more than enough dens exist to meet management objectives, then choose species with long life expectancies and which achieve large diameters⁹.

Management of clumps should be limited to designation of clump areas and protection from other activities. No harvest or TSI should take place within the clumps, minimizing damage to existing dens and ensuring that a range of size classes required by wildlife is provided.

Thinning Prescriptions

In stands where intermediate treatments are to be implemented there is no need to manage clumps. The harsh change in environment does not occur and early mortality should not be a problem. The number of den trees reserved depends upon the management goal. Spacing guides

⁹Species selection guidelines are available from the author at Box 509, Rolla, MO 65401.

are available to help the manager achieve objectives¹⁰. Some other guidelines are as follows:

1. Where young stands less than 50 years of age have been regenerated and the clump method was used, the original clump should be distinguishable and protected as a source of cavity sites.
2. When choosing individual den trees in a stand, it is desirable to have them as evenly spaced as possible.
3. When objectives for den trees greater than 19" dbh cannot be met, select a 10"-19" tree as a replacement. When 10"-19" objectives are not attainable, leave trees as potential den trees which show signs of stress, over maturity or subject to rot. Little is known about which trees will make good den trees, but much depends on individual vigor and previous stresses listed by Conner (1978); Fungal conks, fruiting bodies of species known to cause heart rots (Shigo and Larson 1969, Hepting 1971, Miller 1972, Conner et al. 1976), dead branch stubs (Baumgartner 1939, Shigo and Larson 1969, Conner et al. 1976), old wounds caused mechanically, by lightning or fire (Hepting 1935, Hepting and Hedcock 1937, Stickel 1940, Toole 1959, Shigo and Larson 1969). Also listed are discolored or soft decayed wood in increment corings (Toole 1959, Shigo and Larson 1969, Conner et al. 1976, Jackson 1977). Other possible clues like woodpecker holes or cavities and dead portions of trees may be indicators.

Uneven-aged Management

The Uneven-age Management System will be used most often on 1) units less than 1000 acres of private ownership, 2) lowland hardwood tracts, and 3) public owned upland hardwood tracts where the visual impact of regeneration is undesirable.

Upland Hardwoods:--When the UAM System is implemented, snag and den tree objectives can be met by selecting individual den trees in each stand. Snag objectives should be easily met during TSI operations. When the number of existing den trees is below the manager's objectives, potential den trees may be selected using the recommendations listed above.

Wooded Water Courses

The lowland hardwoods of Missouri are primarily along big river drainages while the riparian habitat may exist along all streams.

¹⁰Den tree spacing guides are available from the author at Box 509, Rolla, MO 65401.

Although most lowlands have been cleared of forest to produce agricultural crops, some lowland hardwoods remain and are managed for waterfowl mast and/or forest products. Management for other resources could soon eliminate existing and potential den trees favoring the younger fast growing individuals, i.e., pin oak, which bear highest yields of mast during the ages of 25-80 years (Fowells 1965).

Lowland Hardwoods--(Wooded, Not Within 200 feet of Permanent Water) A high density of den trees is necessary to meet the requirements of cavity users in the lowland hardwoods. Two methods can be utilized to meet these objectives.

Stands may be designated as old growth, and/or individual den trees may be marked. It is generally accepted that oak species are one of the most desirable as a dominant species in the lowland hardwoods, both for wildlife mast and forest products. Designating old growth stands may result in the eventual loss of oaks to more shade tolerant species; therefore, this may be an undesirable method to use. To prevent the conversion to shade tolerant species it has generally been accepted that an uneven-age management system will remove individual trees from stands, but maintain a dominance of oak species (Putnam et al. 1960). Marking individual den trees should be compatible with this management system. Leaving the 25 trees per acre of the recommended size classes occupies 30% of each acre. Maintaining densities lower than 50% of those recommended may have a compromising effect on respective cavity users.

Snag management in the lowland hardwoods depends on the existing density of den trees and the level of their management. If managers choose to supplement den trees with snags they should follow these guidelines.

1. Attempt to achieve an even distribution of snags.
2. Attempt to leave snags which are relatively rot resistant.
3. When excessive den trees exist they make excellent snags.

Riparian--(Wooded, Within 200 feet of Permanent Water). The objectives for riparian habitats are the same as for lowland hardwoods; however, the habitat should be managed to maximize opportunities to host species requiring cavities. There should be very little closely managed timber cutting in the 100-200 feet zone along stream banks.

If individual trees are managed or removed because they are of high economic value, their removal should not compromise the integrity of the habitat or the quality of the stream. This habitat would lend itself to old-growth classification.

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Snag Management: Options and Incentives for Private Landowners¹

Lorin L. Hicks ^{2/}

Abstract.--Existing and needed incentives for snag management on private lands are discussed. Realistic management objectives must identify areas where habitat can be continuously supplied for minimum viable populations using cost effective methods. The economic and biological feasibility of some options are discussed. Until further incentives are developed, reasonable options include snag retention in riparian zones and limited-use areas, recognition of priority tree species and road management to reduce snag loss to firewood cutters.

INTRODUCTION

A wide variety of forest wildlife requires snag habitat for their existence. Approximately nine percent of all wildlife species in the U.S. Forest Service Northern Region are dependent on dead or dying timber of all size or age classes, including 25 percent of the bird species breeding in Rocky Mountain Forests (Harger 1978, McClelland et al. 1979).

Many questions have been raised regarding the role of private lands in the management of snag-dependent habitat. Some segments of the public feel that high intensity, short-rotation timber management commonly practiced on industrial forestlands is inconsistent with snag management practices for wildlife. Landowners want to know what population levels are required, why private lands are needed to support snag-dependent wildlife, and what costs must be incurred to provide this habitat.

The purposes of this paper are to identify existing and needed incentives for maintaining snag-dependent wildlife on private lands, establish realistic management objectives, evaluate the costs of two management approaches, and recommend snag management options which are compatible with intensive management of industrial forestlands.

INCENTIVES FOR MAINTAINING SNAG-DEPENDENT WILDLIFE

Although there are many options available, few

incentives encourage snag management on private land.

Avian control of deleterious insect pests is commonly promoted as a reason to support insectivorous cavity-nesting birds. However, this argument is unrealistic when compared to the cost of providing the required habitat and the effectiveness of other control methods such as forest chemicals. Birds exert some control on insect populations at endemic levels, but are ineffective in reducing insects at epidemic levels when significant damage occurs to standing forest crops (Bruns 1960, Beebe 1974).

The primary incentive for maintaining snag-dependent wildlife habitat on industrial forestlands stems from a recognition of public concerns and corporate responsibilities.

One way in which public concern is expressed is through the pursuit of wildlife-oriented recreation. A national survey by the U.S. Fish and Wildlife Service in 1980 revealed that 83 million Americans, or 49 percent of all adults 16 years of age or older, engaged in recreational activities directed at the nonconsumptive appreciation of wildlife (Lyons 1982). The extent of participation in these activities reflects not only a substantial demand for the products of wildlife management, but also an increasing interest by the public as to where these products will be produced and who should provide them.

Corporations are owned by stockholders who desire a reasonable return on their investment. Stockholders also expect their companies to operate in a responsible and ethical manner. Consequently, consideration of social and environmental concerns must be recognized as a cost of doing business. Although providing for the needs of snag-dependent wildlife may require extra attention by the private landowner, ignoring the needs of these species invites conflict and restrictive regulation.

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^{2/}Lorin L. Hicks, Wildlife Biologist, BN Timberlands Inc., Missoula, MT.

There is no direct economic benefit which flows to industrial forest landowners as a result of any level of snag management. Perhaps the most effective incentive has yet to come in the form of tax reductions and other methods which allow the landowner to defray the direct costs of providing this habitat in the public interest. However, for legislation of this nature to be passed, the general public as well as the private landowner will have to be convinced that public lands, wilderness areas, and parks do not provide enough habitat to support desired population levels of snag-dependent wildlife.

In the Rocky Mountains, 75 percent (43.2 million acres) of the commercial timberland is in public ownership with industry controlling only 4 percent (2.1 million acres) of the total (Beuter 1980). Private lands are often intermingled with public land in a checkerboard ownership pattern. A definite need for this habitat on private lands must be established in order to determine priorities and mechanisms to offset management costs.

OBJECTIVES FOR SNAG MANAGEMENT

To be effective on intensively managed forests, snag management must have clearly defined objectives. A realistic snag management plan must recognize four points.

First, intensively managed industrial forestlands should not be expected to support more than minimum viable populations of snag-dependent wildlife species. Second, management approaches which do not address all existing wildlife species or uses are not wise investments. Third, snag retention methods must be employed which minimize direct costs or value reductions to the landowner. Fourth, areas must be selected on private lands where the natural processes which perpetuate snags can be preserved as well as the snags themselves.

SNAG MANAGEMENT OPTIONS

In order to discuss the feasibility of snag management options on private lands, a realistic assessment of anticipated costs must be developed. Two management options have been widely discussed. The first approach, which has been employed on public lands, involves the retention of merchantable trees to serve as a continual supply of snags on a "per-acre" basis throughout a stand rotation (Thomas 1979). The second approach, which has been recommended for private lands, uses bird boxes to replace snags and merchantable timber removed during harvest (Bruns 1960, Brawn and Balda 1981).

Snag Retention

In his publication, "Wildlife Habitats in Managed Forests," Thomas (1979) developed an example

to illustrate the impacts of snag retention on wood production in the Blue Mountains of Oregon and Washington. Using this familiar example, I calculated the present-day value of income foregone by employing this technique on 100 acres of commercial timberland (table 1). The basic assumptions are that suitable snags will be continuously supplied to support populations of cavity-excavating species at 60 percent of maximum potential in a ponderosa pine stand managed on a 150-year rotation with a shelterwood silvicultural system.

Table 1. Present-day value of volume forgone on 100 acres to provide snag habitat at the 60 percent level in a ponderosa pine stand managed on a 150-year rotation.

Stand Age (yrs)	Silvicultural Treatment	Volume Forgone (MBF) 1/	PDV Forgone (\$) 2/
0 or 150	Overstory Cut	143.4	11,472.00
80	Thinning	22.8	183.46
100	Thinning	57.0	258.29
140	Shelter Cut	4.2	6.04
Total		227.4	11,919.79

1-Data on volume foregone from Thomas (1979). Conversion rate used was 6 BF = one cubic foot.

2-Stumpage value (average) = \$80.00/MBF, 3% real increase on stumpage value, 6% discount rate.

Total wood volume sacrificed over 150 years to meet these objectives on 100 acres amounts to 228,400 board feet at a present-day value of \$11,919.79, or \$119.20 per acre. To put these figures into perspective, forestland of this type currently sells for \$300-\$400 per acre. Planting costs in this timber type average \$100 per acre. Implementation of this alternative would cost nearly a third of the current market value of the land and exceed the costs of putting a similar site back into wood production.

Bird Boxes

To evaluate a bird box program applied to the same 100 acres, breeding territory sizes were obtained from the literature for secondary cavity-using mammals (Chapman and Feldhamer 1982) and birds (Franzreb 1977). These data indicated that 130 boxes would be required to provide for 60 percent of optimum populations. As shown in Table 2, the total present-day cost of maintaining this program on 100 acres for 150 years amounts to \$6,786.00, or \$67.86 per acre.

Table 2. Cost summary for a bird box program to maintain secondary cavity-using species at 60 percent level for 150 years on 100 acres in ponderosa pine timber type. All units are in dollars.

Expense Item	Per Box 1/	Total Program (130 Boxes)	Present Day Cost 2/
Initial:		\$1,785	\$1,785
Construction	\$11.49		
Installation	\$2.24		
Annual (150 yrs)		\$319	\$5,001
Replacement 1/	\$13.73		
Maintenance	\$1.40		
Total Present-Day Cost:			\$6,786

1-Cost data are from a 3-year bird box feasibility study on public land near Missoula, MT (Rob Hazlewood, Wildlife Biologist, Bureau of Land Management, Missoula, MT, pers. comm.). Annual box loss rate on this study averaged 8% per year.

2-A 6% discount rate was used for present-day cost calculations.

In addition to being expensive, the bird box alternative has a number of biological shortcomings. Most important is the fact that bird boxes alone will not support the major woodpecker species which must excavate holes as part of their courtship behavior. In addition, bird boxes are attractions for predators and parasites (Tardell and Doerr 1982, Pinkowski 1977) and may increase mortality of resident species during winter months. Finally, bird boxes will not provide for the other wildlife uses of snags such as roosting, feeding, and perching sites.

There are actually two different "costs" involved with these options. In the snag retention option, costs represent present-day wood fiber value foregone to meet long-term objectives. With bird boxes, an immediate out-of-pocket expense is required for initial construction and installation, as well as a financial commitment to maintain and replace the boxes over time.

It should be recognized that the anticipated costs for both options would probably be reduced if applied to ownerships larger than 100-acre units. However, these figures indicate that widespread provision for snag-dependent wildlife habitat on a sustained "per-acre" basis represents a substantial and prohibitive cost for an industrial forest landowner.

Logging Residue as Snag Habitat

Logging residue, natural mortality, and the retention of existing snags and cull trees in cutting units can support a variety of snag-

dependent wildlife in a managed forest (Franzreb 1977, Webb 1977, Titterton 1979). However, operations such as broadcast burning and aerial application of fertilizers or herbicides can be complicated by leaving large standing snags within cutting units. This problem may be partially avoided by retaining snags and cull trees on the edge of cutting units. This option has value, but should be recognized as a short-term solution to the problem of providing suitable habitat over time, since no provision is made for replacement snags.

RECOMMENDATIONS

Based on the previous discussion of objectives and feasibility of management options, the following recommendations are offered to integrate snag management into intensive forest management on industrial lands:

1) Utilize riparian zones, inoperable sites, visual zones, and other "limited use" areas for snag management. This reduces direct cost and conflict with other land use objectives, while preserving a continual supply of snags in various size and age classes.

2) Although all tree species are used to some extent by snag-dependent wildlife, attention should be given to retain tree species most preferred by wildlife in the area. For instance, in northwestern Montana the most valuable tree species for wildlife are (in descending order): western larch (Larix occidentalis), ponderosa pine (Pinus ponderosa), cottonwood/aspen (Populus spp.), and paper birch (Betula papyrifera), (McClelland et al. 1979).

3) Road management has become one of the most important tools for snag management. Due to heavy woodcutting pressure in Montana, we have been forced to "write off" snags within 200 feet of an open road. Loss to firewood cutters is a strong argument against leaving snags for wildlife in flat, accessible areas. The problem is widespread, as indicated by Scott et al. (1980) in Colorado, where 97 out of 100 signed "wildlife trees" were removed by woodcutters within two years. Increased road management and public education will be necessary if snag management programs are to be successful on both public and private lands.

SUMMARY

Recognition of social concerns and corporate responsibility are the only existing incentives to provide habitat for snag-dependent wildlife on industrial forestlands. With the abundance of public land present in the west, a clearly defined need for this habitat on private lands must be established. Some options which have been proposed or employed on public lands are not economically feasible for the private landowner. Realistic snag management objectives must be developed which identify areas where a continual supply of habitat

components can be provided for minimum viable populations of all existing species using the most cost-effective methods. Programs to provide habitat for snag-dependent wildlife on industrial forestlands must be balanced with the need to meet economic objectives.

Until more tangible incentives are developed,

the retention of snags in limited use and special management areas, recognition of priority tree species to retain for wildlife, and road management to reduce loss of snags to firewood cutters are the most feasible options for snag management on intensively managed private forestlands.

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Longevity of Snags and Their Use by Woodpeckers¹

Evelyn L. Bull²

Abstract.--Fifty percent of the ponderosa pine (*Pinus ponderosa*) snags and 38% of the lodgepole pine (*P. contorta*) snags were standing 8 years after being killed by the mountain pine beetle (*Dendroctonus ponderosae*) in northeastern Oregon. Trees greater than 50 cm dbh stood longer than smaller trees. Woodpeckers excavated cavities in 15 of the 186 ponderosa pine snags 3 to 8 years after the trees died.

INTRODUCTION

The value of snags to wildlife for nesting, feeding, and perching has been well documented (McClelland and Frissell 1975, Mannan 1977, Thomas et al. 1979, Raphael 1980). Because of their condition, size, or location, however, different types of snags have different values for cavity nesters.

In managed forests, the desired number and kinds of snags can probably be maintained only by deliberate action by resource managers. Information on the number of live and dead trees in a stand, mortality rates, and the rate at which snags fall are needed to predict snag density over time (Bull et al. 1980; Cimon, in press). The time a snag stands, however, is a function of size, rate of decay, species, and cause of death. Few studies have reported the rate at which snags fall (Keen 1929, 1955; Dahms 1949; Lyon 1977; Van Sickle and Benson 1978). My objectives were to determine: (1) how long ponderosa pine and lodgepole pine trees killed by the mountain pine beetle will stand and (2) how woodpeckers use these snags.

METHODS

The study was conducted on the USDA Forest Service (Pacific Northwest Region) Starkey Experimental Forest 35 km southwest of La

Grande, Oregon. This area contains 11 400 ha of mixed conifer forest interspersed with grasslands at elevations of 1 070 to 1 525 m. An outbreak of mountain pine beetle during 1973-80 had killed thousands of lodgepole pine and ponderosa pine trees in the area.

From 1975 to 1977, I marked and measured dbh (diameter at breast height) of 50 lodgepole pine and 186 ponderosa pine trees. I selected trees that had been killed the previous year by bark beetles as indicated by the presence of pitch tubes and brown needles.

Each summer from 1975 to 1982, I recorded the condition of trees (standing, down, or broken) and evidence of feeding and nesting by woodpeckers for each marked tree. In addition, the following characteristics were recorded for 50 lodgepole and 50 ponderosa pines: percent of original bark and needles remaining and the amount of treetop broken off. Snags were grouped in three diameter classes: 25 cm, 25-49 cm, and ≥ 50 cm.

RESULTS AND DISCUSSION

Rate of Fall

No snags fell until the third year after death, and ponderosa and lodgepole pines in the same diameter classes fell at similar rates (figs. 1 and 2). Larger snags fell at a lower rate than smaller ones.

Rate of fall reported in the literature varies (table 1). A variety of conditions including cause of death, soil type (Keen 1955), and size affected longevity. Fire may either retard decay and allow snags to stand longer (Dahms 1949) or increase the rate of fall because no live trees remain to reduce

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² Evelyn L. Bull is Wildlife Biologist, USDA Forest Service, Pacific Northwest Forest and Range Experiment Station, Range and Wildlife Habitat Laboratory, La Grande, Oreg.

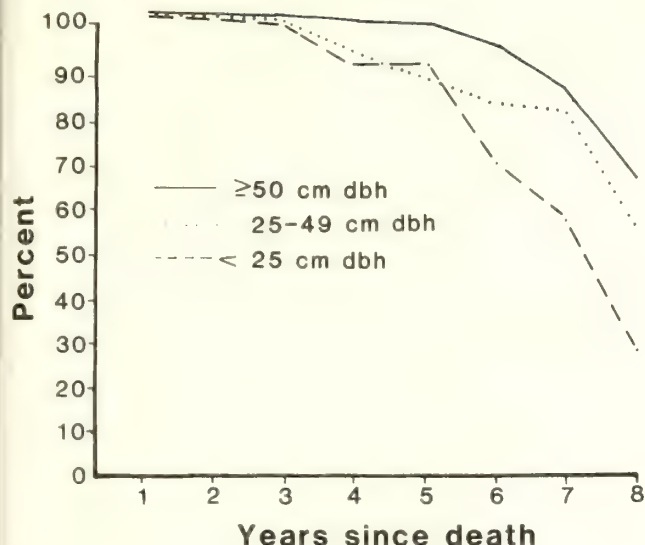


Figure 1.--Percentage of ponderosa pine snags standing, by number of years since death and diameter class, Starkey Experimental Forest, 1975-82.

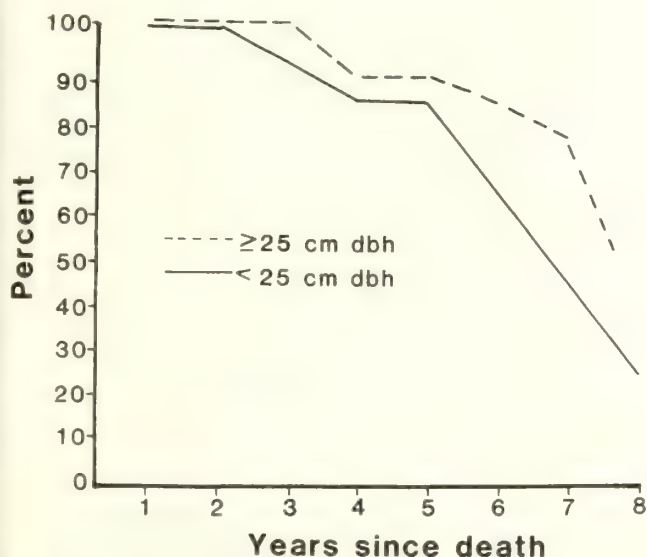


Figure 2.--Percentage of lodgepole pine snags standing, by number of years since death and diameter class, Starkey Experimental Forest, 1975-82.

wind velocities (Lyon 1977). Keen (1955) reported that soil conditions influenced the rate of fall more than did cause of death.

Keen (1929, 1955) and Dahms (1949) agree that large snags fall at a lower rate than

small snags. Because sapwood is more susceptible to decay than heartwood, trees with a thicker core (larger diameter) of heartwood decay slower and stand longer.

Woodpecker Use

There was evidence of feeding by woodpeckers on 82% of the ponderosa pine snags and 92% of the lodgepole snags within the first year after the trees were attacked by bark beetles. Woodpeckers chipped the bark off (scaled) the trunks to obtain bark beetles or larvae. The bark beetle larvae generally remained in the tree 1 year before they developed into adults and moved to a new host tree.

An average of 21% of the trunk surface of the lodgepole pine and 3% of the ponderosa pine was scaled. The lesser amount of activity on the ponderosa pines was probably due to lower insect densities or reduced accessibility because of thicker bark. The scaling occurred on the lower or middle third of the tree trunk on 83% of the trees used by the woodpeckers.

Size of tree, time since death, and broken tops were important in the selection of nest trees. Woodpeckers excavated cavities in 15 of the 186 ponderosa pine snags within the 8 years (table 2). No cavities were found in lodgepole pines or ponderosa pines less than 25 cm dbh. The mean dbh of snags with cavities was 52 cm, which indicated a preference for large diameter trees.

Cavities were excavated in snags that had been dead 3-8 years. Some nest cavities were reused and new nests were excavated in some snags in successive years. Northern flickers (*Colaptes auratus*), Williamson's sapsuckers (*Sphyrapicus varius*), hairy woodpeckers (*Picoides villosus*), and white-headed woodpeckers (*P. albolarvatus*) were observed nesting.

The tops were broken out of 13 of the 15 snags used for nesting. Seventy-seven percent of the cavities occurred within 2 m of the broken top. Woodpeckers excavated here because the wood was probably decayed. Either the break occurred because the wood was already decayed or the wood began decaying when it was exposed by the break. The average cavity height was 16 m. Trees with cavities had 21% (mean) of the top broken off and retained 98% of their bark.

Physical Characteristics

Over the 8 years, the physical characteristics of the snags changed. The needles turned brown in 1975 but most remained on the tree. In 1976, 12% of the original needles remained; in 1977 less than 3%.

Table 1.--Comparison of snags standing reported in five studies

Snags	Keen (1929)	Dahms (1949)	Keen (1955)	Lyon (1977)	This study
<u>Percent</u>					
Ponderosa pine:					
Standing after 8 years	32	60	32-71		64
Standing (25-49 cm) after 7 years	42 ¹				79
Standing (≥ 50 cm) after 7 years	60				86
Lodgepole pine:					
Standing after 8 years				63	38

¹Diameter class was 25-46 cm.

Table 2.--Percentage and number of ponderosa pine snags woodpecker cavities and percentage of snags with cavities that had broken tops

Years since death	Snags 25-49 cm dbh		Snags ≥ 50 cm dbh		Snags with broken tops
	<u>Percent</u>	<u>Number</u>	<u>Percent</u>	<u>Number</u>	<u>Percent</u>
1	0		0		0
2	0		0		0
3	0		2	1	0
4	5	4	7	3	86
5	6	4	9	4	75
6	7	5	16	7	92
7	21	4	17	2	100
8	31	4	33	3	100

¹Numbers are cumulative; a reduction means that snags fell or sample size was smaller.

Bark retention decreased from 100% to 96% on the ponderosa pines and from 100% to 89% on the lodgepole pines over the 8 years. The bark on the lodgepole was thin, dried rapidly, loosened, and fell off more readily than on the ponderosa pine. In addition, more bark was removed by woodpeckers on the lodgepole snags.

The most apparent change in the trees was broken tops (fig. 3). Few lodgepole pines but many ponderosa pines greater than 50 cm dbh had tops broken. The average amount of top broken off was 11%; the range, 5-75%.

The difference in breakage between the two tree species was probably due to physical characteristics. Because the lodgepole pine snags were small in diameter and had thin bark, the wood dried rapidly. Even though there was a high percentage of sapwood, the low moisture content retarded decay. At ground level, however, soil moisture was available, the bark was thicker and retained moisture, which probably encouraged decay. The lodgepole, therefore, were more susceptible to breakage at the base than along the stem. In contrast, the bark of the ponderosa pine snags was thicker, retained more moisture, and was therefore more susceptible to decay and breakage along the entire stem.

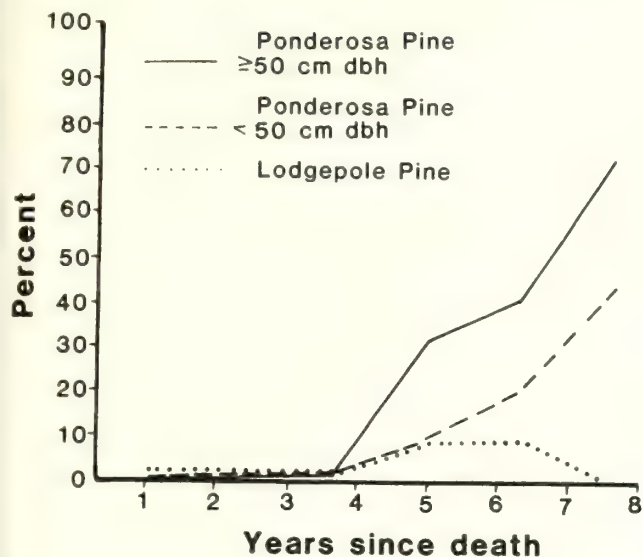


Figure 3.--Percentage of ponderosa and lodgepole pine snags with broken tops, by number of years since death and diameter class, Starkey Experimental Forest, 1975-82.

SUMMARY

Of trees killed by bark beetles in northeastern Oregon, ponderosa pine snags greater than 50 cm dbh stood longer than smaller ponderosa or lodgepole pines. Woodpeckers excavated cavities in larger snags that were dead at least 3 years and had broken tops. The rate of fall of different diameter classes of snags must be considered to provide number of snags over time.

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Potential Woodpecker Nest Trees through Artificial Inoculation of Heart Rots¹

Richard N. Conner, James G. Dickson,
and J. Howard Williamson²

Abstract.--We suggest that the fungus *Spongipellis pachyodon* might be used to artificially create suitable hardwood nest trees for woodpeckers in both young and older trees and when supplies of potential nest trees are limited. Sizes of trees suitable for inoculation, inoculation heights, and densities of snags are suggested for six species of woodpeckers.

INTRODUCTION

The use of snags by North American woodpeckers for both nesting and foraging is well documented (Balda 1975, Scott et al. 1977, Conner 1978, Evans and Conner 1979, Dickson et al. 1983). While a wide variety of sizes and conditions of snags may be suitable for woodpecker foraging sites, only certain conditions of hardwood snags are suitable for nesting. The heartwood of hardwood snags in particular must be softened by fungal decay before woodpeckers can excavate either nest or roost cavities (Conner et al. 1976). While decayed hardwood in pine (*Pinus* spp.) snags may facilitate cavity excavation, pileated (*Dryocopus pileatus*) and red-headed (*Melanerpes erythrocephalus*) woodpeckers can excavate cavities in undecayed pine snags (Conner, unpubl. data).

The increasing demands for timber products in general and firewood in particular (USDA 1982) may further decrease the availability of hardwoods that are suitable for cavity excavation. We report here a successful technique to artificially inoculate two species of heartwood decaying fungi into oaks (*Quercus* spp.). Such a technique would be valuable in forests where it is desirable to create suitably decayed hardwoods for primary cavity nesters at younger tree ages or in greater abundance than would normally occur.

METHODS

Local live cultures of *Spongipellis pachyodon* (Pers.) Kotl. and Pouz. and *Laetiporus sulphureus* (Bull. ex Fr.) Bond. and Sing. were obtained from decaying hardwood trees during the winter of 1979 on the Stephen F. Austin Experimental Forest, Nacogdoches Co., TX. Chips of wood were aseptically cut from pieces of the decaying hardwoods and placed on malt agar. Both cultures subsequently grown from these inoculations were identified by micro- and macroscopic characteristics and growth patterns. Identifications were verified by Frances Lombard at the Forest Products Laboratory in Madison, WI. *Spongipellis pachyodon* was selected as an inoculum because of its demonstrated association with hardwood cavity trees of woodpeckers in Virginia (Conner et al. 1976). *Laetiporus sulphureus* was selected because it was an indigenous hardwood heart rot that we had in culture.

Hollow oak dowels (5 cm long, 1.1 cm dia. with a 0.4 cm hole from end to end) were autoclaved (132°C for 40 min) in a malt extract broth solution (2.5 g malt extract per 100 ml distilled water). An oak-sawdust agar medium (15 g oak sawdust, 11 g malt agar, 2.5 g wheat bran, 1.25 g corn meal and 70 ml of distilled water per pint jar) was mixed, dispensed in pint jars and autoclaved (122°C for 50 min), and then placed on a slanted rack so the agar would harden at an angle of about 60 degrees. Pint jars were inoculated with either *Spongipellis pachyodon* or *Laetiporus sulphureus* after which four of the sterile hollow dowels were placed on top of the slanting growth medium. After 2 to 3 months' growth the hollow dowels were sufficiently infected with fungi for inoculation into oak trees. This technique modifies those used by Silverborg (1959) and Toole (1965, 1966) to inoculate hardwoods with different species of fungi.

Twenty oak trees (both *Quercus falcata* and *Q. nigra*; DBH: mean = 21.9 ± standard deviation = 5.2

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²Richard N. Conner is Research Wildlife Biologist, James G. Dickson is Supervisory Research Wildlife Biologist, and J. Howard Williamson is Forestry Technician, Wildlife Habitat and Silviculture Laboratory (maintained in cooperation with School of Forestry, Stephen F. Austin State Univ.) Southern Forest Experiment Station, USDA, Forest Service, Nacogdoches, TX.

cm; height: 19.7 ± 3.6 m; age: 44 ± 5.9 y) were selected in a forested area on the Stephen F. Austin Experimental Forest, Nacogdoches Co., East Texas. Oaks with obvious signs of decay or injury were automatically excluded from selection. On 11 March 1980, after sterilizing drill bits and drill locations on trees with 70% ethanol, we drilled a 1.5 cm dia. hole 13 - 15 cm deep on the north side of each tree 2 m above the ground with an electric drill. We selected the north side of the trees because it would offer the dampest micro-environment. The holes were drilled slightly upward at an angle of 10° above the horizontal to prevent the entrance of rain water and possible contamination into the holes.

Several *Spongipellis pachyodon* infected dowels were inserted into each hole and stacked tightly against each other in 10 of the drilled oaks. The last dowel inserted into each tree was left protruding from the drill hole to help prevent the tree from sealing the hole. Toole (1967) reported that success of fungal inoculations in hardwoods was much higher if the inoculation hole was kept open. We repeated the same procedure on the other 10 oak trees using *Laetiporus sulphureus* infected oak dowels. We did not attempt to inoculate old knots or limb breaks because of a high probability of being contaminated by other fungi.

Five randomly selected oaks from each group that had been inoculated with *S. pachyodon* and *L. sulphureus* were harvested 27 January 1981. The harvest procedure was repeated again on 20 January 1982. Harvested trees were horizontally and vertically sectioned to determine existence and extent of the fungal infections. Small chips of wood from areas that appeared to be infected were aseptically removed and cultured on malt agar to determine if the fungus subsequently grown was the

same species that was originally inoculated into the tree.

Use of control trees was deemed unnecessary because sections made of the experimental trees with a chain saw readily demonstrated if fungi had been introduced by our inoculation or were present prior to treatment.

RESULTS

Spongipellis pachyodon was successfully inoculated into and recultured from 80% (8 of 10) of the experimental trees (table 1). While all ten of the *Spongipellis* inoculated trees visibly showed signs of heartwood decaying fungi (dis-colored and softened wood present in cross sections), we detected no growth of any fungi on reculture attempts for two trees. We strongly suspect that the fungus present in these two trees was *S. pachyodon*. There was no visual evidence in the cross sections of these ten experimental trees indicating the presence of any fungal infections prior to our inoculation.

Laetiporus sulphureus was also successfully inoculated into and recultured from 80% (8 of 10) of the experimental trees (table 1). However, in one of these eight trees a different species of fungus (*Phellinus gilvus* (Schw.) Pat.) was also detected when trying to reculture *L. sulphureus*. The two remaining experimental trees were also infected with fungi. One of these trees appeared to have been infected with *Phellinus gilvus* prior to our inoculation. *Phellinus gilvus* was cultured from heartwood tissue during reculturing attempts. The last of the ten trees had a fungus that did not appear to be *Laetiporus sulphureus* and, unfortunately, we were unable to successfully culture

Table 1.--Growth of heartwood decaying fungi inoculated into oaks (*Quercus falcata* and *Q. niger*) in East Texas.

	Species of Fungi	
	<i>Spongipellis pachyodon</i> n = 10	<i>Laetiporus sulphureus</i> n = 10
Success of reisolation	80%	80%
Average 2 year growth above inoculation	31.8 ± 10.1 cm ¹	18.4 ± 5.8 cm
Average 2 year growth below inoculation	25.4 ± 11.3 cm	11.2 ± 1.6 cm
Average annual vertical growth	28.6 cm	14.8 cm
Average annual horizontal growth	5.2 x 2.7 cm	2.6 x 1.4 cm
Other fungi detected in reculture	None	<i>Phellinus gilvus</i> in 2 trees

¹Mean $\pm$ standard deviation.

the fungus. We suspect that this unidentified fungus may have been introduced when we originally drilled the tree.

Spongipellis pachyodon grew vertically within the experimental trees at approximately twice the rate of *Laetiporus sulphureus* (table 1). *S. pachyodon* spread at an average vertical rate of 28.6 cm per year while *L. sulphureus* only spread 14.8 cm vertically per year. In three of the five *Spongipellis* inoculated trees that were harvested after 2 years growth white hyphal tissue could be seen growing out of the drill hole around the protruding dowel, almost as if the fungus was beginning to form an external conk or sporophore.

The horizontal growth of *S. pachyodon* averaged 5.2 by 2.7 cm/y (an elliptical area, table 1). This was also approximately twice the dimensions of horizontal growth demonstrated by *L. sulphureus* (2.6 by 1.4 cm/y). The elliptical horizontal growth pattern was caused by the linear nature of the inoculation dowels in the tree. The long axis of the ellipse was parallel to the inoculation dowels.

DISCUSSION AND CONCLUSIONS

The technique used to inoculate heart rots into oaks was quite successful. Although *Spongipellis pachyodon* was recultured from only eight of the ten experimental trees, we believe our actual success was 100%. Our actual success with *Laetiporus sulphureus* was less than that with *S. pachyodon*. This, combined with the greater growth rate of *S. pachyodon*, strongly suggests that *S. pachyodon* would be the preferred fungus to use when inoculating trees for woodpeckers.

In the present study we selected only oak trees to test the success of fungal inoculation. *Spongipellis pachyodon*, however, infects many other species of hardwoods. Conner et al. (1976) detected the fungus in *Quercus alba*, *Q. rubra*, *Q.*

prinus, *Q. coccinea* as well as *Acer saccharum* and *Carya tomentosa*. Also, an association between hardwood woodpecker nest trees and *S. pachyodon* has already been demonstrated; ten of the 12 hardwood nest trees that Conner et al. (1976) studied intensively were infected with *S. pachyodon* as the primary decay fungus.

Spongipellis pachyodon grew within the heartwood of the oaks much faster in vertical directions than horizontally. This is caused in part by compartmentalization of wood tissue (Shigo and Marx 1977). Because *Spongipellis pachyodon* spreads slower horizontally than vertically, enough time must elapse for decay to spread to sufficient diameters to house woodpecker cavities. Trees would have to be inoculated at least 6 years prior to intended use for pileated woodpeckers. Six years might permit the decay column to expand to approximately 31 x 16 cm in diameter, a minimum size for pileated cavities (table 2). It is necessary for the decay column to grow to this sufficient diameter because pileated woodpeckers that are excavating cavities in oaks and most other hardwoods usually stop when they encounter undecayed wood at the bottom and on the sides of nest cavities (Conner et al. 1976).

The time required for sufficient growth of decay from inoculation until potential use by other woodpecker species will be shorter than that for pileateds (table 2). It is also important to note that the sapwood in hardwoods must also be decayed before a snag will be suitable as a nest site for downy woodpeckers and northern flickers because these two species typically cannot excavate through undecayed sapwood (Conner et al. 1976).

When artificial inoculation of hardwood trees is feasible we suggest that *Spongipellis pachyodon* be used as the inoculum as described in our methods section. However, trees should be inoculated at heights close to average nest cavity heights for individual woodpecker species and in

Table 2.--Woodpecker cavity and nest tree characteristics.

Species	Average ¹ cavity depth	Average ¹ cavity diameter	Time for decay	Average nest height	Optimum D.B.H. ranges of nest trees
	(cm)	(cm)	(years)	(m)	(cm)
Downy woodpecker <i>Picoides pubescens</i>	18	9	3	4.8	15-25
Hairy woodpecker <i>P. villosus</i>	35	11	4	8.8	25-35
Pileated woodpecker <i>Dryocopus pileatus</i>	48	20	6	13.6	45-65
Northern flicker <i>Colaptes auratus</i>	28	14	5	8.5	30-44
Red-bellied woodpecker <i>Melanerpes carolinus</i>	30	10	4	7.6	36-53
Red-headed woodpecker <i>M. erythrocephalus</i>	30	10	4	7.0	40-60

¹ Conner, unpubl. data--nest cavities from both Virginia and Texas.

trees of the appropriate DBH (table 2, Conner et al. 1975, Jackson 1976). If inoculations are made lower in trees than the average nest height, more time would elapse before the fungus would grow to sufficient dimensions at heights favorable to woodpeckers; low nests would probably have increased predation pressure (Dennis 1969, Kilham 1971, DeWeese and Pillsmore 1972). Most woodpeckers would be able to detect the presence and location of heart rots in potential nest trees by percussing the tree and possibly sensing a "special" resonance that indicates a suitable site for excavation (Conner et al. 1976, Conner, pers. obs.).

Numbers of snags (dead or mostly dead trees) needed as cavity sites by woodpeckers to support varying percentages of population maximums (table 3, revised from Evans and Conner 1979) are important if a forest manager decides to create additional potential nest sites by artificial inoculation. The numbers of snags indicated in table 3 include snags for one cavity nest and three roost sites. It is important to consider roost cavity numbers because individual woodpeckers of many species use several during the course of a year, a behavior that may reduce the probability of predation. Our estimates on the number of roost sites preferred by woodpeckers is probably low. Also included in the number of snags needed is a reserve of 9 snags for each cavity required by a pair of woodpeckers during a year. This includes a margin for snags that are unusable for nesting or roosting, a reserve of snags for replacements, and a supply for secondary users (Bull and Meslow 1977, Evans and Conner 1979). Because competition for cavities often occurs, the needs of secondary cavity nesters must be considered. While some of the reserve of snags will be used as foraging substrate, the numbers of snags recommended for cavity requirements will in no way meet the complete foraging needs of the woodpecker species. Until additional data indi-

cate a revision is needed, we suggest that our estimates are conservative. Quantitative data are needed to show what percentage of standing snags are actually suitable for cavity excavation. The numbers of snags we have suggested can be used as a general guideline for forest resource managers wishing to augment available cavity habitat for both primary and secondary cavity nesters.

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Table 3.--Numbers of snags required to provide cavities to support varying percentages of woodpecker population maximums. (Revised from Evans and Conner 1979 for southern forests)

Species	Snags needed per 4.0 ha for cavities to maintain listed percentages of population maximums				
	Excellent	Good		Fair	Poor
	100	80	60	40	20
----- (number) -----					
Downy woodpecker <i>Picoides pubescens</i>	40	32	24	16	8
Hairy woodpecker <i>P. villosus</i>	20	16	12	8	4
Pileated woodpecker <i>Dryocopus pileatus</i>	5	4	3	2	1
Northern flicker <i>Colaptes auratus</i>	5	4	3	2	1
Red-bellied woodpecker <i>Melanerpes carolinus</i>	27	22	16	11	6
Red-headed woodpecker <i>M. erythrocephalus</i>	20	16	12	8	4

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The Use of High-Cut Stumps by Cavity-Nesting Birds¹

Michael L. Morrison, Martin G. Raphael, and Robert C. Heald²

Abstract.--This paper discusses the use of high-cut stumps by cavity nesting birds. Although high-cut stumps are less hazardous and present little revenue loss compared to taller snags, virtually no information is available on the use of such stumps by birds. Literature sources and research results indicate that few species will readily use such stumps. Creating high-cut stumps is economically feasible, however. It is recommended that high-cut stumps be used as replacements for tall snags only in areas of potential safety hazard.

INTRODUCTION

The use of snags by cavity nesting birds has received increased attention as more forested land has come under intensive management for timber production. As is well known, snags are required as roosting and nesting sites by numerous birds--the density of primary and secondary cavity nesting birds is often directly related to snag density (e.g., Scott 1979, Raphael 1980). Unfortunately, the presence of snags is often in conflict, either real or imaginary, with the conduct of certain forest management practices. For example, snags can pose fire hazards, are sometimes in the path of ground and/or aerial forestry equipment, and can act as health hazards if they fall near roads, trails, or buildings (e.g., see McClelland and Frissell 1975, Scott 1978). In addition, snags are often a readily available source of fuel wood. Thus while snags are a requisite for many forest birds, there are many competing demands for their disposition.

The deterioration of snags complicates their management. As summarized by Thomas et al. (1979), a snag deteriorates from the time the tree dies until its collapse; not all stages of deterioration are suitable for a particular bird species. Even if enough snags are left in a clearcut to provide 100% of the potential population of cavity nesters, this 100% level will immediately begin to decline as the snags continue deteriorating, fall, and otherwise become unsuitable (see Thomas et al. 1979). Therefore, not only are the absolute number and sizes of snags important, but these requisite

snags must be provided continuously in a forest stand to assure a diversity of snag decay classes.

Given the competing demands for snag utilization, and the fact that snags must be supplied during all successional stages of the forest, various proposals have been advanced for ensuring that the needs of cavity nesting birds will be met, including killing trees through herbicide injection, girdling, and use of explosives (e.g., Conner 1978, Bull et al. 1981). Creating artificial nest cavities via routing has also been proposed (Carey and Sanderson 1981). Although snags created through such artificial means are apparently suitable for cavity nesting birds, such snags still present various safety hazards, and are also subject to harvest as fuel wood.

An additional proposal for supplying the needs of cavity nesting birds is the creation of high-cut stumps. The process of "high-stumping" creates snags that are short (usually < 2 m) compared to most natural or artificial snags. These high-cut stumps are less hazardous than taller snags and little revenue in board footage is lost by creating a small versus a tall snag.

As outlined by Thomas et al (1979), birds apparently require snags of a certain minimum height and diameter. The question arises, then, as to whether high-cut stumps will be suitable replacements for taller snags. Although Kroll et al. (1980) suggested that "high-stumping" will provide excellent foraging sites for woodpeckers, we know of no study that has analyzed the use of stumps by cavity nesting birds.

The purpose of this paper is to identify likely results of a program using high-cut stumps prior to actual initiation of such a program on a large scale. We suggest species that will likely use such stumps, as well as an economic analysis of integrating high-cut stumps into a forest management plan.

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²Michael L. Morrison is Assistant Professor of Wildlife Biology, Martin G. Raphael is Staff Research Associate, and Robert C. Heald is Manager, Blodgett Forest Research Station, University of California, Berkeley, Calif.

Little original information was available on nest and nest-tree heights for cavity nesting birds. Some authors have relied heavily on data presented in the "Bent Life History Series" or on other previously published summaries; much published information is thus repetitive. We made no attempt to analyze data by geographic region because of the paucity of original information; we have, however, generally confined our survey to western North America.

Our survey of the literature indicated that few species readily nest in snags less than 2 m tall (Table 1). Although Bent (see Table 1 for citations) gave the minimum nest heights of most species as near 2 m, the remaining citations indicated that the mean nest height is usually much higher. The only species that appeared to consistently use stumps for nesting was the White-headed Woodpecker (scientific names given in Table 1). Although a detailed analysis of the nesting habits of this species is apparently lacking, most authorities indicated that this species regularly uses snags < 2 m tall.

Bull (1978), Bull et al. (1980), and Thomas et al. (1979) all gave 1.8 to 2.0 m as the minimum nest height for the White-headed Woodpecker and the Northern Flicker (see also Table 1). Other authorities, however, indicate that the flicker usually uses taller snags for nesting (Table 1). Bull et al. (1980) and Thomas et al. (1979) also gave 1.8 m as the minimum acceptable nest height for the Black-backed Woodpecker. Here again, the remaining citations gave much higher nest heights for the Black-backed Woodpecker. Bull et al. (1980) were alone in suggesting that 1.8 to 2.0 m was the minimum acceptable nest height for the Downy Woodpecker, Mountain and Chestnut-backed chickadees, and Western and Mountain bluebirds. It should be noted that E. Bull and J. W. Thomas both conducted their research in northeastern Oregon, a possible reason for the similarity in many of their recommendations.

Cunningham et al. (1980) found (in Arizona) that secondary cavity nesting birds used snags with heights ranging from 2 to 36 m. However, only 2% of the snags (stumps) in the 0-4 m height interval were used; 63% of all snags used were over 20 m tall. They concluded that secondary cavity nesters used cavity heights in proportion to their availability, although on one study area a slight trend for the use of the higher cavities was evident.

The use of stumps and snags by cavity nesting birds was surveyed by Raphael (unpubl. data; see also Raphael 1980, Raphael and White, in press) in the eastern Sierra Nevada. Only one species (Mountain Chickadee) used stumps under 1 m in height (Table 2). Mountain Chickadees also used stumps 1 to 2 m tall, as did the White-headed Woodpecker, Northern Flicker, Mountain Bluebird, and House Wren; the use of stumps by the latter

three species was rare. Use of stumps (snags) under 2 m tall accounted for about 33% of all nest sites for the chickadee; White-headed Woodpeckers were rare in the study area but 25% of their nests were in snags under 2 m tall. Note (Table 2) that only 9% of all nest sites were in snags under 2 m in height; the majority (71%) of all nests were in snags over 5 m tall. Thus while certain species did use stumps for nesting, the distribution of nest sites by height was markedly skewed to the use of tall snags.

Raphael (unpubl. data; 1980) also surveyed the availability of stumps and snags in the study area. Stumps, now defined as < 1.5 m tall, accounted for 60.2% of all standing dead trees, while snags > 1.5 m tall accounted for 39.8% of this material. If snags were defined to include only trees > 38 cm dbh, then stumps accounted for 89.5% of all standing dead trees. In contrast, over 90% of all nests were in snags over 1.5 m in height. Thus, cavity nesting birds appeared to be preferentially using tall snags relative to stumps.

Data presented in this paper indicates that few species will accept stumps as nest sites. One cannot infer nest-site "selection," which denotes that an actual choice between two or more potential nest sites is being made by an individual, without experimental manipulation of stump and snag availability (see below). The data did indicate, however, that the White-headed Woodpecker and the Mountain Chickadee accepted stumps as nest sites. The Northern Flicker and Black-backed Woodpecker may also use stumps as nest sites occasionally.

It is important to note, however, that most primary and secondary cavity nesting birds only infrequently use stumps for nesting. Data indicates that while the range of heights used as nest sites often included stumps, the mean nest height was usually much above 2 m. Further, nest heights can be positively skewed towards taller snags.

Thomas et al. (1979) reported minimum nest heights for cavity nesting birds. Conner (1979) has questioned the use of minimum standards as management guidelines. Conner argued that providing only minimum habitat factors, such as snag height or diameter, may be biologically unsound, and for certain species may cause a decline in abundance because of reduced reproductive success. For example, birds that nest lower than normal in trees may risk increased predation. Conner further suggested that trees should be provided that span either side of the average diameter and height so that the chance of breeding success can be maximized. It is also doubtful that a species could be "forced" to accept smaller snags by eliminating larger ones (Conner 1979). It is important to note that even the minimum nest (or snag) height apparently acceptable for certain species, 1.8 to 2.0 m, is near the maximum height that high-cut stumps can be safely produced (i.e., without the aid of ladders).

Table 1. Nest and tree heights (m) of cavity nesting birds summarized from literature sources.

Species	Nest height		Tree height		Reference ¹
	$\bar{X}$	range	$\bar{X}$	range	
Primary cavity nesters					
Lewis' woodpecker	7.3		11.4		F
<u>Melanerpes lewis</u>	9.1				I
		2-33			J
Acorn woodpecker			12	9-15	E
<u>M. formicivorus</u>		2-12			J
Yellow-bellied Sapsucker			9	6-12	B
<u>Sphyrapicus varius</u>	2.9-6.9	1.1-10.8			C
	12	7-18	18	13-24	E
	17.2	6.1-22.3			H
	4.6				I
		1.7-10			J
Red-breasted Sapsucker	12.8		20.5		F
<u>S. ruber</u>					
Williamson's Sapsucker	2.4-10.3	0.8-16.9			C
<u>S. thyroideus</u>	7	3-18	16	7-30	E
	11.2		19.9		F
	4.6				I
		1.7-2.0			J
Downy Woodpecker			6	3-9	B
<u>Picoides pubescens</u>		2-11			D
	7	6-8	13	12-15	E
	4.7-4.9	1.0-11.6	5.8-8.3	1.5-19.8	G
	4.6				I
		1-17			J
Hairy Woodpecker			9	6-12	B
<u>P. villosus</u>		3-17			D
	10	6-15	18	10-21	E
	4.8		13.7		F
	8.8	2.4-19.8	13.0	4.0-26.5	G
	18.2	7.9-41.8			H
	4.6				I
		1.3-33			J
White-headed Woodpecker	2.0		3.8		F
<u>P. albolarvatus</u>	1.8				I
		1.7-5			J
Three-toed Woodpecker			9	6-12	B
<u>P. tridactylus</u>	10	9-11	16	12-21	E
	4.6				I
Black-backed Woodpecker			9	6-12	B
<u>P. arcticus</u>	2.8		16.8		F
	1.8				I
		1.3-4			J
Northern Flicker			9	6-12	B
<u>Colaptes auratus</u>		3-18			D
	11	3-21	19	7-27	E
	7.7		12.7		F
	8.5-13.7	2.7-21.9	12.4-22.5	9.1-36.0	G
	11.4	3.0-26.8			H
	1.8				I
		0.3-33			J

Table 1 (continued).

Species	Nest height		Tree height		Reference ¹
	$\bar{X}$	range	$\bar{X}$	range	
Pileated Woodpecker <u>Dryocopus pileatus</u>		5-17	18	12-21	B
	7.5-13.6	5.5-19.2	9.8-20.3	7.3-36.6	D
	15.0	7.0-24.1			G
	9.5				H
		5-28			I
					J
Pygmy Nuthatch <u>S. pygmaea</u>	2.9	1.3-6.1			A
	13	2-24	18	9-31	E
	4.7		6.1		F
	9.1				I
		3-8			J
Red-breasted Nuthatch <u>Sitta canadensis</u>	9	4-15	16	4-26	E
	9.2		15.1		F
	27.6	7.0-56.4			H
	4.6				I
		1.7-120			J
Secondary cavity nesters					
Tree Swallow <u>Tachycineta bicolor</u>	12	7-15	21	15-25	E
	4.6		10.3		F
	4.6				I
Violet-green Swallow <u>T. thalassina</u>	12	2-24	19	7-37	E
	4.6				I
		>1.7			J
Mountain Chickadee <u>Parus gambeli</u>	2.4	2.4-3.3			A
	9	2-18	15	3-37	E
	3.5		8.1		F
	1.8				I
		0.7-27			J
Chestnut-backed Chickadee <u>P. rufescens</u>	18.4	1.8-44.8			H
	1.8				I
		<3			J
White-breasted Nuthatch <u>S. carolinensis</u>	2.6	1.5-6.4			A
	9	4-15			E
	5.7		10.2		F
	4.6				I
		5-17			J
Western Bluebird <u>Sialia mexicana</u>	3.7	1.2-7.9			A
	12	6-21	18	9-24	E
	1.8				I
Mountain Bluebird <u>S. currucoides</u>	7	1-12	14	7-24	E
	4.5		6.6		F
	1.8				I

¹ A = Cunningham et al. (1980:Table 8); B = Evans and Cogner (1979:Tables 2 and 3); C = Crockett and Hadow (1975:Table 1)³; D = Conner (1978:Table 2); E = Scott et al. (1980:Table 3); F = Raphael (1980:Table 11); G = Conner et al. (1975:Table 1)³; H = Mannan et al. (1980:Table 3); I = Thomas et al. (1979:Appendix 19)²; J = Bent (1939, 1942, 1946, 1948, 1949).

² Values represent minimum nest heights.

³ Values are the range of means found for several study sites.

Table 2. Use of stumps and snags for nesting by primary and secondary cavity nesting birds in the Sagehen Creek Basin, Tahoe National Forest, California (n = 568 nests).

Species	0 - 1m		1 - 2m		2 - 3m		3 - 4m		4 - 5m		> 5m	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Lewis' Woodpecker	0	0.0	0	0.0	0	0.0	0	0.0	1	2.7	36	97.3
Red-breasted Sapsucker	0	0.0	0	0.0	1	2.0	1	2.0	0	0.0	48	96.0
Williamson's Sapsucker	0	0.0	0	0.0	1	2.0	0	0.0	2	4.0	47	94.0
Hairy Woodpecker	0	0.0	0	0.0	0	0.0	1	4.3	2	8.7	20	87.0
White-headed Woodpecker	0	0.0	3	25.0	2	16.7	3	25.0	3	25.0	1	8.3
Black-backed Woodpecker	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	8	100.0
Northern Flicker	0	0.0	1	1.5	5	7.4	6	8.8	4	5.9	52	76.5
Tree Swallow	0	0.0	0	0.0	1	7.1	4	28.6	0	0.0	9	64.3
Mountain Chickadee	22	16.8	22	16.8	15	11.5	5	3.8	8	6.1	59	45.0
Red-breasted Nuthatch	0	0.0	0	0.0	0	0.0	2	6.7	1	3.3	27	90.0
White-breasted Nuthatch	0	0.0	0	0.0	2	8.0	5	20.0	4	16.0	14	56.0
Pygmy Nuthatch	0	0.0	0	0.0	1	3.6	5	17.9	6	21.4	16	57.1
Western Bluebird	0	0.0	0	0.0	0	0.0	1	50.0	1	50.0	0	0.0
Mountain Bluebird	0	0.0	1	2.7	1	2.7	8	21.6	3	8.1	24	64.9
American Kestrel ¹	0	0.0	0	0.0	0	0.0	1	7.7	3	23.1	9	69.2
Brown Creeper ¹	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	17	100.0
House Wren ¹	0	0.0	2	9.5	1	4.8	2	9.5	2	9.5	14	66.7
European Starling ¹	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	2	100.0
Total	22	3.9	29	5.1	30	5.3	44	7.7	40	7.0	403	71.0

¹ American Kestrel (*Falco sparverius*); Brown Creeper (*Certhia americana*); House Wren (*Troglodytes aedon*); European Starling (*Sturnus vulgaris*); scientific names of other species in Table 1.

Although our analysis indicates that few species will readily use high-cut stumps should they be provided, only experimental creation of such stumps will give a clear indication of the suitability of such structures as nest sites. We are currently conducting a study that both creates high-cut stumps (see below) and manipulates the density of natural snags. Until such pilot studies are complete, we advise extreme caution be used in attempting to integrate high-cut stumps into a forest management plan. Some preliminary guidelines follow:

1. High-cut stumps should be used only where populations of White-headed Woodpeckers, flickers, and chickadees are present. The use of such stumps

should be directed only towards these species and not be used to reduce the overall number of snags deemed necessary to maintain populations of other cavity nesters.

2. Stumps should be as tall as possible and meet the diameter (dbh) requirements for the species of interest (e.g., see Thomas et al. 1979, Raphael and White, in press).

3. Stumps should be used as a replacement for tall snags only in areas of potential safety hazard (e.g., along roads and trails, near buildings). High-cut stumps along roads will also reduce hazards to timber operators and make equipment operation easier.

4. Guidelines for management of tall snags should also be followed; for example, stumps should be created in groups, rather than as scattered individuals (e.g., see Bull 1978, Evans and Conner 1979).

5. All high-cut (and natural) stumps should be monitored for use by cavity nesting birds; the presence of nest excavations and feeding sign (see Kroll et al. 1980) should be recorded.

ECONOMIC ANALYSIS: A CASE STUDY

The probable economic cost of creating high-cut stumps can be estimated by combining several direct expenditures, values foregone, and intangibles. The direct costs include time spent selecting trees for "high stumping," administrative cost involved in incorporating new contractual language, coping with legal restrictions, and any increase in logging costs. The principal values foregone include the wood left in high stumps and any expected loss in site productivity incurred by altering originally planned residual stand conditions. Intangible costs may include disruption of existing timber faller training programs, overcoming professional resource managers' biases, public education, and a potential shift of attention away from other wildlife habitat needs.

At Blodgett Forest Research Station, El Dorado County, California, timber harvesting operations and planning are conducted in a fashion quite similar to both timber industry and federal timber sale programs. The Forest is constrained to comply with all existing California laws and procedures that apply to non-federal forest land in California. Furthermore, operations separate sale of logs from timber harvesting contracts and harvest planning. This facilitates accurate accounting of actual costs. The following example illustrates the costs incurred while incorporating high-cut stumps into harvesting activities at Blodgett Forest. The data are drawn from a variety of partial cutting harvests (including selection, intermediate thinning, seed tree seed step, and overstory removal forest regeneration methods) in young growth (50 to 80 year old) mixed conifer-oak stands on highly productive mid-elevation (1300 meters) sites (index height 30 to 40 meters at 50 years of age, breast height) in the central Sierra Nevada of California. Pre-harvest and residual stand densities varied considerably.

At Blodgett Forest the only quantifiable direct cost of creating high-cut stumps is higher timber falling rates. Additional falling time results from operating the chainsaw in an unusual position and taking extra caution to mitigate the added risk of injury inherent in nonstandard tree falling. Assuming each high-cut stump tree requires three minutes more to fell than the average tree indicates added cost of about \$2 each.

Insignificant additional time is spent by tree marking crews in selecting "high stump" trees. Marking rules are simply modified to include proper guidelines.

Logging costs on average tractor operable terrain should not be significantly adversely affected

by high-cut stumps. Certainly the high-cut stumps would have to be avoided by skidding machines; this potentially could disrupt planned skid trails and increase residual stand damage. Conversely, slightly higher than normal stumps are often prescribed on the inside of skid trail turns to act as "rub trees" and prevent residual stand damage. Some additional breakage in felled trees and residual stand damage might be incurred as timber fallers are forced to adjust falling lead to avoid high stumps. On balance, such costs are either negligible or can be mitigated by judicious selection of trees marked by the forester for use as high-cut stumps.

The unquantifiable direct cost involved dealing with existing state regulations. In 1973 California passed a new Forest Practice Act (CFPA 1973) considered to be among the most stringent in the nation. The Act and associated administrative code requires approval of a Timber Harvesting Plan (THP) before any commercial timber harvesting may take place on non-federal lands in California. Among the numerous rules developed to implement the Act is one (954.2, Southern District Rules) that restricts stumps to a maximum height of 30 cm. The intent of this rule is to reduce the supposed adverse visual effects of stumps and to increase utilization of wood resources. The effect of Rule 954.2 is to render high-cut stumps purely for wildlife habitat illegal. Circumventing this legal problem required filing THP amendments for each proposed harvest area plus the considerable cooperation of Forest Practice Inspectors representing the California Department of Forestry.

The value of marketable wood left is clearly the largest single cost in high-cut stumps. A simple computation of average volume left per stump would seem in order. However, the peculiarities of various scaling rules tends to confound the issue. Assuming an average high stump is 60 cm (dob), 1.4 m taller than normal stumps, and standing trees are valued at \$16 per cubic meter (\$100 per thousand board feet), the value of wood left in the forest is about \$7 per high-cut stump. To whatever extent trees can be selected that have a portion of the high-cut stump cull due to existing disease or damage, the value of wood left in the forest would be reduced. So long as high-cut stumps are selected from trees that would have been cut anyway, there should be no added loss due to poorer site occupancy or distorted residual stand structure. This probably means that groups of high-cut stumps are actually interspersed with residual live trees. These costs may be reduced by selecting trees with low wood value because of cull or species differences in value. The wood left in high-cut stumps also represents volume that timber operators will not harvest. Since these loggers would have to do no more work to yard and load the wood left in high-cut stumps if it was still attached to a log, the dollars that would have been paid for harvesting the wood is value foregone.

Intangible costs are by definition difficult to evaluate. Certainly most forest land managers who have been involved in programs designed to increase wood fiber utilization will be somewhat reluctant to appear to be retreating on low stump height requirements. Many foresters will undoubtedly view a high-cut stump program as further erosion of

their perceived principal mission of wood production. The general public may view the stumps as eyesores. All of these problems are surmountable by advertising the value (if they have some) of high-cut stumps in standard programs designed to communicate the habitat needs of wildlife.

In summary, the accountable cost of creating high-cut stumps given the conditions at Blodgett Forest are approximately \$9/stump. Most other costs and (nonhabitat) benefits are negligible or compensating assuming reasonably well applied sale administration and planning. In our case, creating one group of 3 to 5 high stumps per 4 hectares results in an average timber sale net revenue reduction of \$9 per hectare.

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Direct Habitat Improvements — Some Recent Advances¹

Andrew B. Carey and John D. Gill²

Abstract.--Den boxes can be made smaller, more accessible, and more resistant to predators by adding an inside shelf just below the entrance. Boxes placed on the lee sides of trees were preferred by squirrels in winter but not in spring or summer. And den boxes can raise the carrying capacity of young forest for sciurids. Using a chain saw to create tree cavities to be covered with a wooden faceplate is more efficient than routing dens with a drill or creating dens with a chain saw and chisel. Small woodpeckers will excavate cavities in styrofoam cylinders. These "plastic trees" offer some intriguing management and research applications.

INTRODUCTION

Carey and Sanderson (1981) reviewed the literature³ on formation and value of cavities and provision and use of nest boxes; thus, we will cite only recent literature in this paper. Animals that use cavities receive two major benefits: shelter from the elements (especially for energy conservation) and safety from disturbance, especially predation (Alerstam and Hogstedt 1981, McComb and Noble 1981a, Slagsvold 1982). A principle objective of direct habitat improvements for cavity-using wildlife is to restore the benefits lost through silvicultural, agricultural, or mining activities. Attempts to make up for the lack of naturally formed cavities in second-growth and managed forest fall into two general categories: provision of artificial structures and acceleration of the cavity-forming process. Our purpose is to describe ways of efficiently and effectively providing shelter for some cavity-using wildlife. We discuss artificial structures, acceleration of cavity formation, and why, when, and where direct habitat improvements are appropriate.

ARTIFICIAL STRUCTURES

Wooden boxes are the most commonly provided artificial structures for denning, nesting, or roosting. Metal, cement and sawdust, rubber (tire), and polystyrene structure also are used. Boxes can and should be tailored for particular species; plans (and species-specific dimensions) are readily available (Burt 1979, Gary and Morris 1980, Hardin and Evans 1977, Yoakum et al. 1980). The metal, wooden, and rubber structures are well known and widely used. Scott et al. (1980) reported that cement and sawdust boxes are preferred in Europe because they are more durable, harbor fewer ectoparasites, and are better insulators than wooden boxes. Here we present an unpublished nest-box design for squirrels (*Sciurus*, *Tamiasciurus*, and *Glaucomys*), a discussion of optimum nest-box orientation, and a new development--plastic trees.

An Improved Nest Box For Squirrels

The best-known nest box for squirrels is the modified Barkalow-and-Soots box (fig. 1; Yoakum et al. 1980). Vagn Flyger⁴ designed a wooden box (fig. 1) that is superior to the Barkalow-and-Soots box: it is smaller, therefore more portable, easier to place, and cheaper to construct; the entrance is square and at the corner of the face board, making construction simpler; it is easy to make the entrance size small (and line it with sheet metal to prevent gnawing) during construction to produce a box that excludes gray squirrels (*S. carolinensis*) and fox squirrels (*S. niger*) but admits flying squirrels (*G. volans* or *G. sabrinus*);

¹Paper presented at the Snag Habitat Management Symposium, Northern Arizona University, Flagstaff, 7-9 June 1983.

²When most of the work reported here was done, Carey was research wildlife biologist and Gill was project leader, Northeastern Forest Experiment Station, USDA Forest Service, Morgantown W. Va. Now, Carey is research coordinator, Old Growth Forest Wildlife Habitats Program, USDA Forest Service, Olympia, Wash. and Gill is research wildlife biologist, Northeastern Forest Experiment Station, USDA Forest Service, Amherst, Mass.

³Reprints available from Carey. Forestry Sciences Laboratory, 3625 93rd Avenue SW, Olympia, WA 98502.

⁴Flyger, V. 1983. Personal conversation. Department of Animal Science, University of Maryland, College Park, Md.

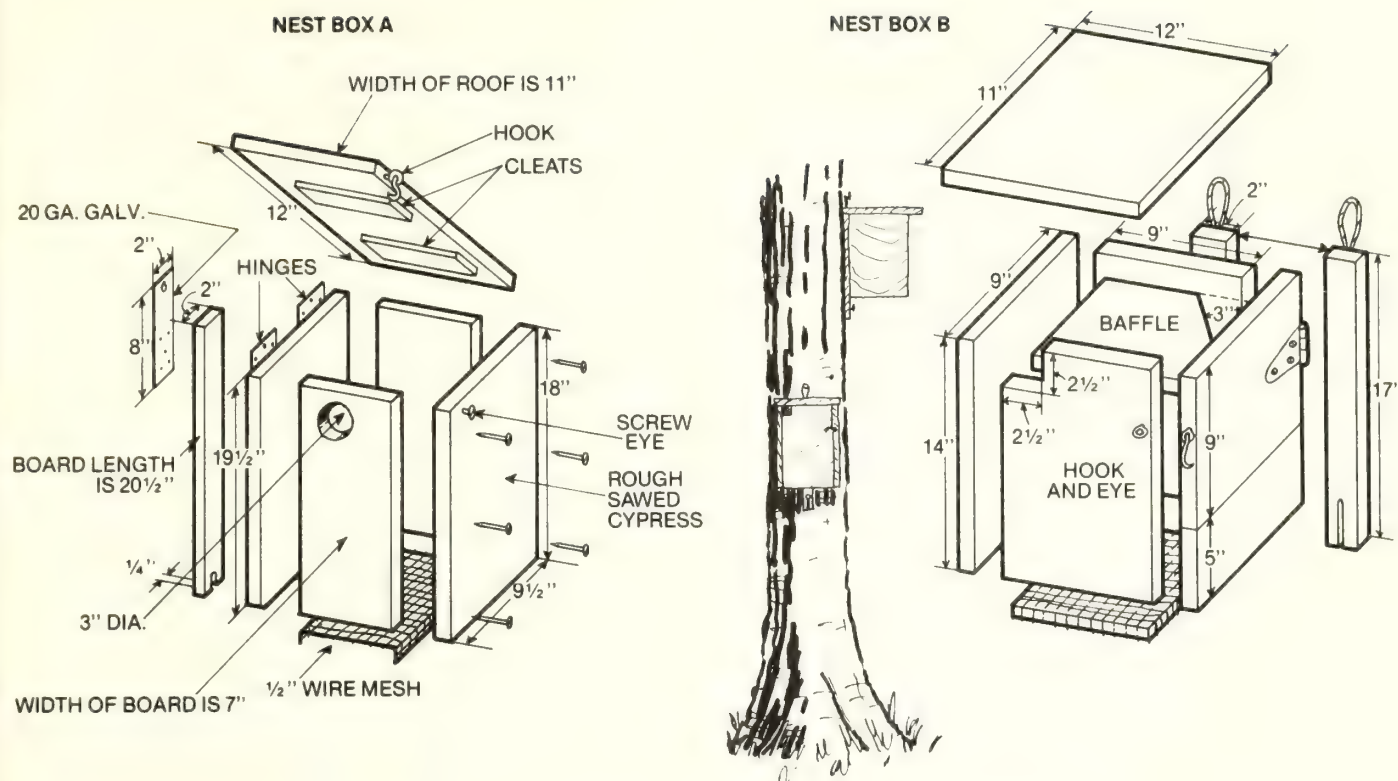


Figure 1. Comparison of two nest boxes: A is the Barkalow-and-Soots box, B is the Flyger box. Note the shelf in box B and the smaller size of B. Wooden bottoms result in higher use than wire-mesh bottoms.

the shelf, just below entrance height with a second entrance in the far corner, makes the box more resistant to predators, allows the box to be smaller, and provides a protected loafing spot for squirrels (which often rest on top of the Barkalow-and-Soots box), the shelf probably helps to prevent heat loss; access to the box interior is through the side, making it easier to inspect and clean the box and to capture animals using the box. If the box is to be used primarily to capture animals, the shelf should be hinged or narrowed to 8 cm to make it easier to remove animals. Flyger has erected more than 3,000 of his boxes in Maryland and has used them for several years in his research on gray squirrels, fox squirrels (including the endangered *S. n. cinereus*), and southern flying squirrels. Flyger recommends using wooden bottoms, but not mesh bottoms, in the nest boxes. He found that boxes with wooden bottoms received much greater use than boxes with mesh bottoms.

Gray squirrels, fox squirrels, red squirrels (*T. hudsonicus*), and southern flying squirrels (up to 25 per box) readily used the boxes. Screech owls (*Otus asio*), European starlings (*Sturnus vulgaris*), and other animals (mammals, birds, amphibians, reptiles, and invertebrates) were occasionally found in the boxes. Use of nest boxes by a wide array of species is common (Carey and Sanderson 1981; McComb and Noble 1981b, 1981c, 1982). If blowfly (*Apaulina* spp.)

parasitism in nest boxes is common in the area in which boxes will be placed, constructing a bowl-shaped floor for the boxes can reduce the level of parasitism (Pinkowski 1977). European starlings often usurp boxes set out for other birds, but Flyger observed that gray squirrels ate the eggs and young of European starlings.

Placement of Nest Boxes

Sanderson (1975) gave directions on placement of nest boxes, but he did not recommend a particular side (aspect) of the tree or an aspect for the box entrance. Because construction and placement of nest boxes is labor intensive and costly, the boxes should be placed optimally to provide maximum shelter and safety for the squirrels and in such a way as to obtain the greatest use by squirrels. Franz Pogge⁵ (under the direction of J. D. Gill) conducted a study to determine if gray squirrels and southern flying squirrels preferred boxes on particular sides of trees or with entrances facing particular directions. He also

⁵Pogge, F. P. 1981. Squirrel den exposure and multiple winter den use. Final Report, Study FS-NE-1702-18; unpublished report. USDA Forest Service. Forestry Sciences Laboratory, Morgantown, W.Va.

wanted to know how a surplus of boxes would be used and what the effect of boxes would be on the leaf-nest building behavior of gray squirrels.

Methods

Forty Barkalow-and-Soots nest boxes were placed in the 0.85-ha enclosure described by Sanderson and Berry (1972). Four boxes were attached to each of 10 trees, 7 m above the ground, on the NE, SE, SW, and NW sides of the trees (prevailing winter winds were from the NW). The boxes had entrances on their sides and next to the tree; thus the entrances were at right angles to the box orientation. One-half of the boxes had their entrance to the right, one-half to the left. The boxes were examined for use by gray squirrels and southern flying squirrels during 1979-81. Ten or 11 gray squirrels were kept in the enclosure, close to the optimum described by Berry et al. (1978). As an ancillary study in 1979, one box was placed on each of the wire-mesh walls (with entrances facing N, S, W, or E) of eight 3 x 3-m pens. Thus, none of the boxes was protected from the wind by a tree trunk. Two gray squirrels were kept in each of six pens, one in the seventh, and three in an eighth pen. The boxes were checked for use twice in January and once in March.

Results

It was common for gray squirrels to use more than one box for nesting and for more than one gray squirrel to be found in a box. Gray squirrels clearly preferred boxes on the SE side of trees for nests during late fall and winter (table 1). Other boxes were used for feeding. No clear preference for nest entrance location was apparent when all boxes were considered (table 2), but

Table 1. Proportions of 40 nest boxes used by gray squirrels during November-March: effect of box aspect.

Period	Inspections ¹ of boxes (N)	Aspect of tree stem where box was attached			
		SE	SW	NW	NE
Jan-Mar 1979	2	0.50	0.05	0.05	0.00
Nov-Mar 1979-80	7	0.21	0.13	0.14	0.04
Nov-Mar 1980-81	7	0.17	0.06	0.13	0.23
Average		0.27	0.08	0.11	0.09

¹Inspection dates were 19 January, 7 March 1979; 11 November, 17 December, 1 and 21 January, 12 February, 3 and 24 March 1979-80; and 10 and 25 November, 10 December, 12 and 28 January, 26 February, and 23 March 1980-81.

Table 2. Proportions of 40 nest boxes used by gray squirrels during November-March: effect of box-entrance aspect.

Period ¹	Aspect of box entrance				Preferred aspects
	SE	SW	NW	NE	
1979	0.00	0.35	0.05	0.20	SW
1980	0.03	0.17	0.13	0.20	NE
1981	0.03	0.07	0.24	0.24	NW, NE
Average	0.02	0.20	0.21	0.21	SW, NW, NE

¹Numbers of inspections and their dates are in Table 1.

there was a clear preference for NE entrances over SW entrances to boxes on the SE side of trees (2:1 preference). In the 3 x 3-m study, all of the squirrels used the same box for nesting and the other boxes for feeding. There was a clear preference for E-facing entrances. Southern flying squirrels also preferred boxes on the SE side of trees. Up to 14 southern flying squirrels were found in single boxes and up to 42 used boxes in the 0.85-ha enclosure at any one time. Southern flying squirrels also used unoccupied boxes for feeding and defecating. Supplemental food (corn) was provided for the squirrels in the enclosure.

During spring and summer, there was no preference for box or entrance orientation by gray squirrels, including females rearing litters. The use of multiple boxes and leaf nests was common. Females commonly moved their litters to and from leaf nests and nest boxes. In 1978, five females moved their litters 21 times during July to September. One squirrel moved her litter three times, two moved their litters four times, and two moved their litters five times. The mean distance moved was 25.2 m, ranging from 18.5 to 82.0 m. We believe that 10 movements resulted from the technician's inspections of the boxes.

The surplus of boxes did not inhibit leaf-nest building. Nine to eleven gray squirrels and 10 boxes were in the enclosure during 1973-78; the gray squirrels built an average of 14 leaf nests per year. After 30 boxes were added in 1979, the squirrels built 24 leaf nests; in 1980 they built 12 leaf nests before the study ended in July. Leaf-nest building seemed tied to individual behavior because adult squirrels varied greatly in nest-building and consistently built nests (six nests in 3 years). Three to seven other squirrels built nests in any one year. The death of the nest-building pair resulted in a lower than average number of nests being built in the succeeding 3 years, even though the number of adult squirrels was kept the same.

In addition, to the squirrels, deer mice (*Peromyscus* sp.), white-breasted nuthatches (*Sitta carolinensis*), northern flickers (*Colaptes auratus*), and a variety of invertebrates used the boxes.

Conclusion

In the winter, gray squirrels preferred nest boxes that were sheltered from the wind and whose entrances faced the morning sun. Flying squirrels had similar preferences. Thus, we recommend that nest boxes be placed on the lee side of trees with entrances facing east. The placement should be taken into account during construction so that the side door is away from the tree to facilitate maintenance or inspection.

Leaf-nest building is unrelated to the availability of nest boxes (and presumably natural dens) and the presence of leaf nests does not suggest a lack of other nest sites.

Surplus boxes (those not required for nesting) are used for feeding and other activities; presumably, they help squirrels conserve energy and protect them from predators. The importance of such additional refuges to squirrels is unknown.

Plastic Trees

Tom Grubb⁶ proposed that polystyrene (Styrofoam) cylinders might provide easily constructed portable roost and nest-cavity substrate for woodpeckers that could be used as a research tool or to mitigate the effects of clearcutting or surface mining. Peterson⁷ tested the cylinders in the laboratory and found that excavating in polystyrene was not deleterious to the health of woodpeckers. Downy woodpeckers (*Picoides pubescens*) excavated 51 roost cavities in forty-two 242 x 22-cm cylinders during field tests. Carolina chickadees (*Parus carolinensis*) and house wrens (*Troglodytes aedon*) subsequently used 30 of the cavities as nest sites. Raccoons (*Procyon lotor*) destroyed 18 cavities; Peterson suggested using aluminum funnels of the kind used on bird feeders to protect the cylinders. Grubb (1982) used the cylinders to study the snag-height preferences of downy woodpeckers. Ongoing research includes using polystyrene cylinders to attract woodpeckers to clearcuts on the Wayne-Hoosier National Forest to control the red oak borer (*Enaphalodes rufulus*). Further details are presented by Grubb elsewhere in this symposium.

ACCELERATING CAVITY FORMATION

Sanderson (1975) suggested cutting 8-cm-diam. branches to leave 15-cm stubs on trees to accelerate cavity formation; but the cavity-forming process would still be long, perhaps 6-20 years. Conner (1978) suggested girdling trees to provide foraging and cavity substrate for woodpeckers. We have

observed a number of girdled hardwoods (girdling was done to improve timber values) in the Appalachians that had been fed upon or that had had cavities excavated in them. But such trees rot from the outside in (sapwood to heartwood), and once the rot had progressed far enough to allow excavation the trees became fragile and easily destroyed. Conner et al. (1981) examined herbicide-killed trees and believed that the potential of these trees as cavity substrate was good, though none of the 41 trees examined had cavities.

McComb and Ramsey (1983) reported that herbicide-killed trees were acceptable foraging sites for cavity-nesters and that 5-11% of the trees were excavated for cavities; they recommend the technique for supplying a sustained yield of dead trees. But Conner et al. (1981) cautioned that the herbicides might have deleterious effects on woodpeckers or their prey. Bull et al. (1981) suggested using explosives to blow out the tops of trees to accelerate cavity formation, but treetops became tangled in the canopy and the explosive failed to completely shear tops that already contained rot.

Carey and Sanderson (1981) reported the results of boring holes in trees and concomitantly inoculating the trees with fungi. The process was arduous and required a portable generator; inoculation of fungi had little benefit because of the ubiquitousness of decay-causing fungi. Although the rudimentary cavities were quickly used by deer mice and flying squirrels, the trees began to heal by forming callus over the holes. Gano and Mosher (1983) created cavities by removing a section of a tree with a chain saw, excavating wood with a chisel, and replacing the removed section (with a hole bored through it). The procedure was laborious and time consuming (1-1/2 hours per tree) and 37% of the trees fell within 1 year. Here we provide an update on routing trees to accelerate cavity formation and an unpublished technique (and new equipment) for creating cavities with a chain saw.

Routing to accelerate cavity formation

After 3 years, 18% of the holes had been closed by callus, but 80% of them were being used by southern flying squirrels for feeding and denning (Carey and Sanderson 1981). By the fifth fall after routing, southern flying squirrels and deer mice had begun raising young in the routed holes; the number of young reared is unknown. In year five, 28 of 139 holes were being used as nests by southern flying squirrels and 53 holes were being used for feeding. Deer mice used five holes. Thus, 62% of the holes were being used in the fall. Six years after routing, 19 nests of southern flying squirrels, 6 nests of deer mice, and 1 bird (species unknown) nest were found in the holes in the fall. Total use was 40%, and 20% of the cavities had been closed by callus. Thus, it appears that the quality of the cavities had improved (young were being raised) and that closure by callus was slowing (only an additional 2% closed in 3 years). The cavities were still unattractive to birds.

⁶Grubb, T. C. 1979. Personal correspondence. Department of Zoology, Ohio State University, Columbus.

⁷Peterson, A. W. 1981. Artificial trees as a nest and roost hole substrate for woodpeckers. 34 p. Unpublished M.S. Thesis, Ohio State University, Columbus.

New routing equipment was developed⁸ that was safe and easy to use and that could create gourd-shaped cavities with small entrances. But a portable generator still was required and the small entrances would be even more subject to closure by callus than those we previously routed (if routing had been in a live hardwood). Although the improved equipment produces a readily usable cavity, we are not reporting the design here because we believe that the following technique is superior.

Creating cavities with a chain saw

Using a chainsaw to create a hole in a tree and covering the hole with a wooden faceplate with an entrance hole in it to produce a cavity for secondary cavity-nesters (fig. 2) was first done on the Avery Ranger District of the Idaho Panhandle National Forest.⁹ Mark Orme created 40 cavities in dead trees in clearcuts in 1978. By the following year, 80% of these cavities were being used by birds. In 1979, another 12-15 were created, and all were used by the following year. The principal species using the cavities were mountain bluebirds (*Sialia currucoides*) and house wrens (*Troglodytes aedon*), but at least one red-breasted nuthatch (*Sitta canadensis*) occupied one of the cavities. In 1980, cavities were constructed in living trees, but it was not possible to determine their use. Eli Milodragovich⁸ later developed an improved chain saw that is safe to use for creating cavities when the operator is fully trained and experienced, and has standard safety equipment for tree climbing and sawing (Swedish climbing ladders, safety belts, gloves, chaps, ear protectors, goggles). Several features of the improved chain saw are important: the chain saw must have a compression release for easy, safe starting on the ladder and must be compact and light; a sprocket-nose blade must be used (solid nose blades are quickly damaged); an 8-inch blade must be fashioned from a 12-inch blade (fig. 3); a low-profile, antikick chain--a "chisel chain"--must be used, and a kickback guard (fig. 3) must be installed to act as a chain brake. If the chain kicks back, the guard contacts the wrist and is pivoted to a position over the bar and chain, preventing chain contact with the operator. Faceplates, entrance holes, and cavity size can be tailored to particular species. Faceplates are fashioned before going into the forest and should be attached to the tree with nonferrous nails. Actual cavity construction in live hardwood trees (even in below-freezing weather) requires 8 minutes or less and is less arduous than routing holes with a drill. The cavity thus constructed would be available for immediate use. Callus formation would serve only to further fasten the faceplate to the tree. Cavities produced in this

SCHEMATIC FOR CONSTRUCTING CAVITIES: HOLE SIZE IS EXAGGERATED RELATIVE TO TREE DIAMETER.

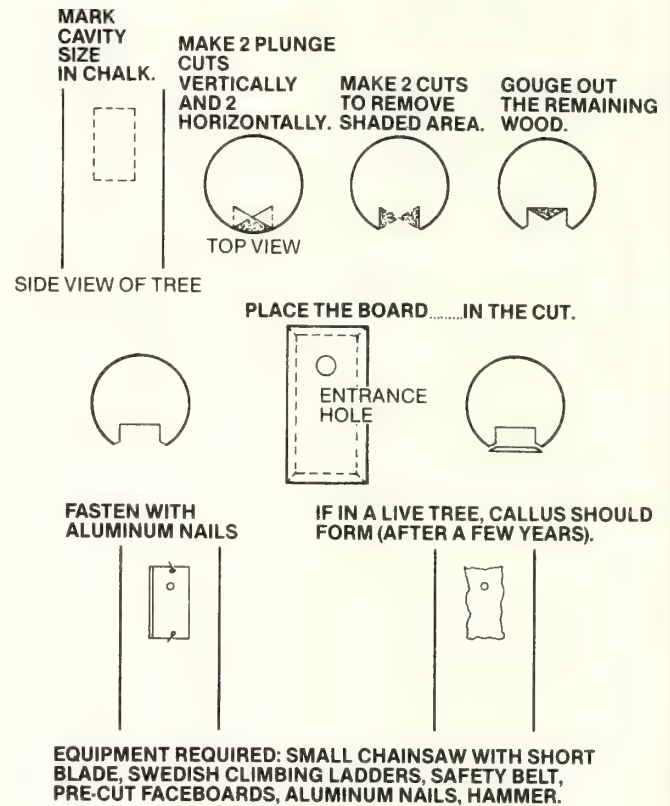


Figure 2. A procedure for constructing cavities with a chain saw.

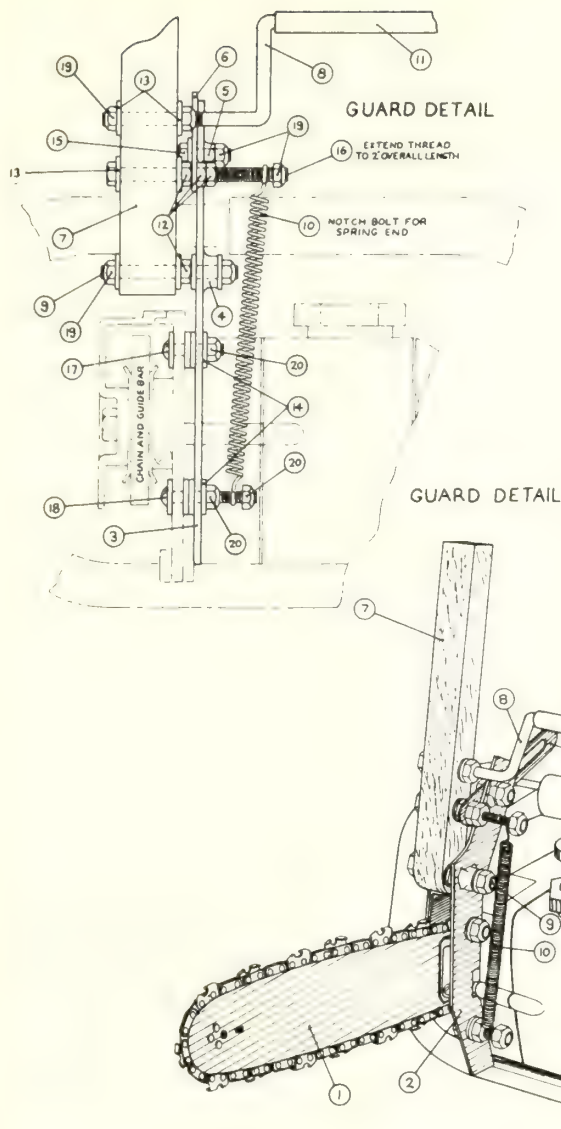
manner should be more secure, better insulated, and longer lasting than nest boxes, and in time would allow the same succession of users that naturally formed cavities do. These cavities also would be unobtrusive and therefore less subject to vandalism than nest boxes.

IMPLEMENTING DIRECT HABITAT IMPROVEMENTS

Providing artificial structures and accelerating cavity formation are not substitutes for amenable environments for cavity-nesting wildlife, or even substitutes for cavity trees. A cavity in a tree is but one part of a varied resource: the tree may be infested with insects that provide food for cavity-using birds; its roots may have hypogeous ectomycorrhizal fungi that produce fruiting bodies that are important food for squirrels and small mammals; other fungi infect the trunk and limbs; the tree may dependably produce large amounts of mast; more than one species may use cavities in the tree or crevices in the bark; the cavities themselves may accommodate a succession of users; a live cavity-tree may die while standing to produce substrate for excavation of cavities by other species; or the tree may fall and provide food and shelter for still other species. The tree itself is but one element of an environment that produces food, cover, suitable microclimate, and

⁸Milodragovich, E. 1980. Demonstration on the National Forests in North Carolina. USDA Forest Service Equipment Development Center, Missoula, MT.

⁹Orme, M. L. 1983. Personal conversation. Targhee National Forest, St. Anthony, ID.



MATERIALS LIST			
NO.	PART NAME	REQ.	SHEET
1	GUIDE BAR	1	CHAIN SAW GUIDE BAR 12\"/>

DESIGNED FOR USE WITH HOMELITE MODEL SEZ-AO



This is a REDUCED PRINT, full size print available upon request.

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CHAIN SAW FOR MAKING TREE DENS		
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Figure 3A. Modifications to chain saws that are used for constructing cavities. Drawing 1 of 2.

behavioral stimuli. Different environments harbor different mixes of species, and environmental structure may influence which species can coexist. Thus, meeting legal mandates to ensure viable populations of all indigenous wildlife will not be accomplished through the techniques described in this paper.

The technique and structures are appropriate for some kinds of research. They can be of great value in interpretative programs on natural history. They can be used for attracting or increasing the density of certain species in areas used by the public to observe wildlife; for example, along nature trails. They promote consideration for wildlife on private lands through extension services. Direct habitat improvements have successfully increased populations of gray squirrels, fox squirrels, wood ducks (*Aix sponsa*), American kestrels (*Falco sparverius*), eastern bluebirds (*Sialis sialis*),

and other species; Yoakum et al. (1980) and Carey and Sanderson (1981) provided reviews. For example, Nixon and Donohoe (1979) reported that 6-8 nest structures per hectare increased the density of gray squirrels in 30-to 60 year-old hardwood forests where dens were lacking but food was abundant. In many of our second-growth forests, snags and cavity-trees are few or lacking. Using the techniques discussed can allow some cavity-dependent wildlife to exist where they would otherwise be absent. Such mitigative measures have been and can be applied on reclaimed surface mines.

Direct habitat improvements may prove to have substantial value in attracting, restoring, or increasing populations of certain species of wildlife for a variety of purposes. Artificial structures are commonly used in the South to attract purple martins (*Progne subis*) to control mosquitoes and heartworm in dogs. The use of nest boxes in

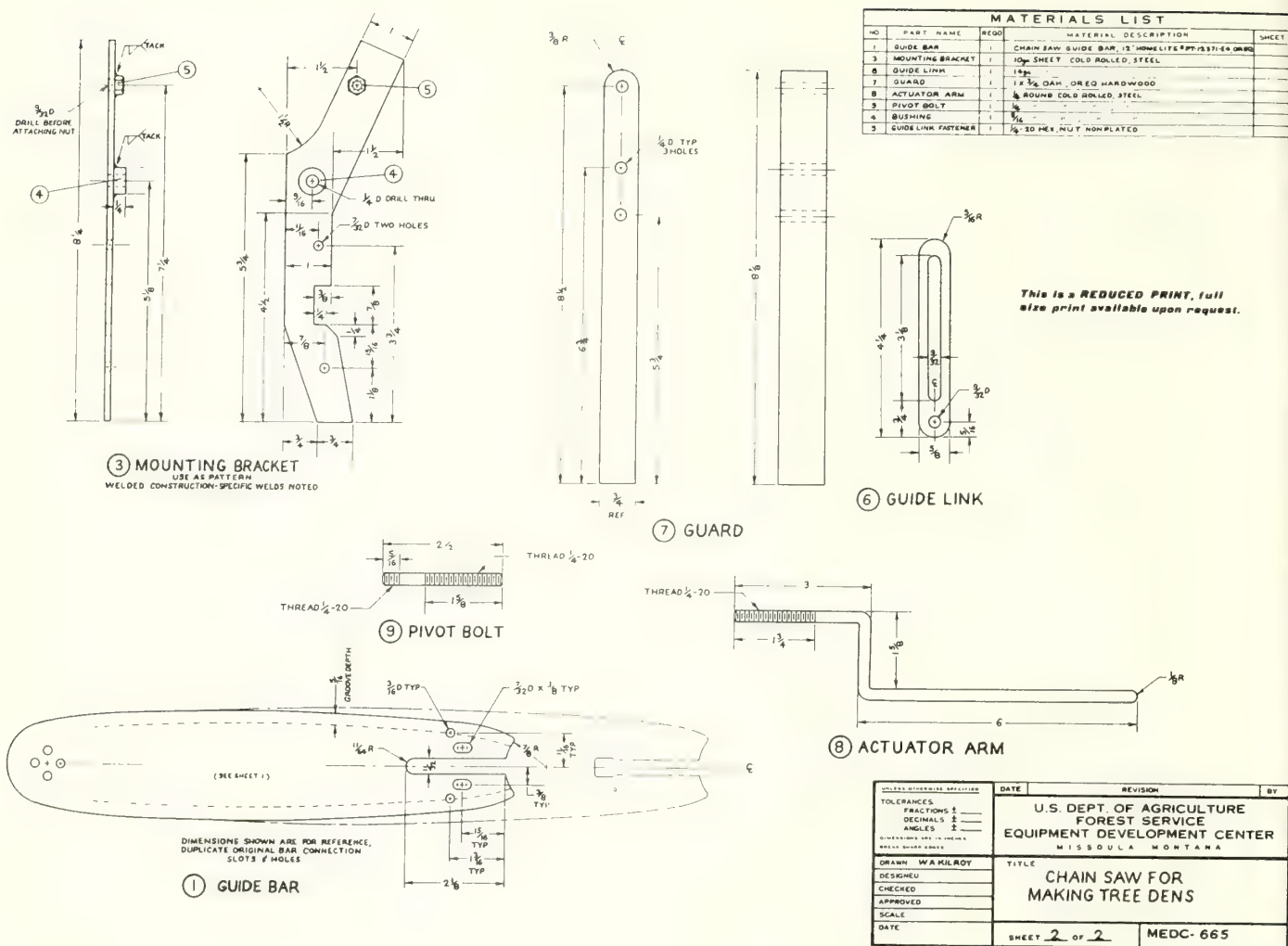


Figure 3B. Modifications to chain saws that are used in constructing cavities: Drawing 2 of 2.

Europe to attract insectivorous birds for pest control is well known (Yoakum et al. 1980). Smith (1975) suggested that nest boxes could raise the density of white-footed mice (*Peromyscus leucopus*) to aid in the control of gypsy moths in young, even-aged hardwood forests. Tom Grubb's work has potential for integrated pest management in U.S. forests. Joe Witt¹⁰ is evaluating the use of nest boxes for increasing populations of northern flying squirrels to increase prey availability in areas managed for spotted owls (*Strix occidentalis*). As with any management effort, installation of artificial structures or acceleration of cavity-forming processes should be subject to cost-benefit

analysis. Costs of artificially providing shelter for cavity-using wildlife also can be used in cost-benefit analyses of other resource management activities.

ACKNOWLEDGMENTS

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¹⁰Witt, J. W. 1983. Trapping northern flying squirrels. Paper presented at the annual meeting of the Oregon Chapter of the Wildlife Society, Sun River, Oregon, February 23-25, 1983. Roseburg District, USDI, Bureau of Land Management, Roseburg, Oregon.

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Habitat Selection Related to Resource Availability Among Cavity-Nesting Birds¹

Timothy Brush², Bertin W. Anderson, and Robert D. Ohmart³

Abstract.--Variation in snag species and abundance appeared to explain most of the habitat selection patterns observed in five cavity-nesting riparian species over a three-year period. All species except Ash-throated Flycatchers were most common in areas with cottonwood or willow snags, which have relatively soft wood and are preferred nest sites. Classification of habitats on the basis of nest-site characteristics was useful and should be considered in other habitat selection studies.

INTRODUCTION

Why do animals occur where they do and what causes them to select certain habitats? Interest in habitat selection was stimulated by the reviews of Hilden (1965) and Lack (1954, 1966). Krebs (1970) and Kluijver (1951) concluded that birds selected optimal habitats on the basis of resource abundance and breeding success. Others have concentrated on the psychological basis of habitat selection (Klopfer 1963, Wecker 1963). The experimental approach is desirable but not always possible, due to the limitations of the laboratory environment.

Availability of nest sites is thought to be the main determinant of habitat selection in cavity-nesting birds (von Haartman 1957). Nest-box studies have shown that distribution and abundance of secondary cavity-nesting birds are greatly influenced by nest site availability (Lack 1954, 1966; von Haartman 1957). This is especially true in managed or successional habitats that have high resource levels but otherwise lack nest sites (Pinkowski 1977).

Primary cavity-nesters (families Capitonidae, Picidae, Paridae, and Sittidae) depend greatly on availability of nest sites. For example, Red-cockaded Woodpeckers (*Picoides borealis*) occur only in areas containing live pine (*Pinus* spp.) trees infected with "red heart" fungus (*Fomes pini*), in which they are able to excavate nest

holes (Jackson 1977). Yeager (1955) showed an increase in woodpeckers concurrent with an increase in number of snags (dead trees). This could be due to increased nest sites and foraging substrates, as woodpeckers frequently forage on snags (Mannan et al. 1980).

Anderson and Ohmart (1978) showed a correlation between densities of snags and densities of cavity-nesting birds and suggested that snag availability limited cavity-nesting populations in southwestern riparian situations. They discussed snags in terms of abundance only. We suggest that snag species are also important in riparian habitats and discuss here the value of cottonwood (*Populus fremontii*) and willow (*Salix gooddingii*) snags in various riparian habitats.

Given that snags are an important component of the habitat for riparian cavity-nesters, we attempt to answer the following question: Does variation in snag species explain the distribution of cavity-nesting species in the lower Colorado River valley? In answering this question we propose a habitat classification based on snags and not on plant community type. Our classification is designed to minimize the effects of food resource variability on bird density. We also discuss seasonal fluctuations in bird densities and habitat selection. For woodpeckers, we discuss the relationship between morphological characteristics, excavating ability, and habitat selection.

METHODS

Transects varying in length from 600 to 1650 m were established in relatively homogeneous stands of riparian vegetation. The sampled area extended laterally 125 m from the transect on both sides. For the original study (Anderson and Ohmart 1977a), each habitat type was sampled in approximate proportion to its occurrence in the lower Colorado

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²Ph.D. Candidate, Department of Biological Sciences, Rutgers University, Piscataway, NJ.

³Faculty Research Associate and Associate Director, respectively, The Center for Environmental Studies, Arizona State University, Tempe, AZ.

River valley. For the purposes of this study, transects were classified into groups, or snag habitats, based on predominant snag species present.

Estimates of bird densities in each study site were obtained using the Emlen (1971) line-transect technique (modified by Anderson et al. 1977). Each study site was censused three times per month. We calculated mean densities over a three-month period or season, involving nine censuses per study site and a minimum of 30 censuses per snag habitat. Results presented are for winter (December-February) and summer (May-July), 1977-1979. This number of censuses was determined to be adequate for reliable density estimates (Anderson and Ohmart 1977b, Engel-Wilson et al. 1981) in the area studied.

Snag Counts

A snag count was conducted on all study sites. The count area extended laterally 15 m from the transect line on both sides. All trees ≥ 14 cm in diameter with 50-100% dead canopy were counted and converted to snags per 40 ha.

Transects were grouped according to species of snags in the following manner: as cottonwood, if cottonwood snags were present (regardless of other snag species present); as willow, if willow snags were present in the absence of cottonwood; as honey mesquite (*Prosopis glandulosa*) or screwbean mesquite (*P. pubescens*) if present in the absence of cottonwood or willow snags; and as snagless if no snags were present. Cottonwoods and willows were considered to be softwood species compared to hardwood mesquite species (Hepting 1971). More than one vegetation habitat type was usually present in each snag habitat type (table 1).

Foraging Behavior

Foraging behavior of woodpeckers was recorded in all study sites to better understand the foraging niche of each species. We were primarily interested in two parameters: (1) use of snags as a foraging substrate; and (2) foraging method (pecking, probing, gleaning, or hawking).

Snag Use

Several study areas were chosen to examine snag preferences in different plant community types. There was one study area of 20 ha each in cottonwood-willow and honey mesquite vegetation types. There was a 20-ha and an 80-ha area in screwbean mesquite habitat. Ten areas totalling 93 ha were examined in salt cedar (*Tamarix chinensis*) habitats.

In all study areas detailed observations were made of snag availability and usage by cavity-nesters. A snag was considered to be "used" if one or more completed woodpecker cavities were present. Additionally we searched for active nests or roosts throughout riparian habitats in the lower Colorado River valley.

RESULTS

Snag Density

Snag densities varied from 121 screwbean mesquite snags per 40 ha to 215 cottonwood snags per 40 ha (table 2). All snag habitats appeared to be homogeneous in species composition, with the exception of cottonwood, which had relatively high numbers of willow (104/40 ha) and screwbean mesquite (109/40 ha) snags. Variances in snag

Table 1.--Relationship between vegetation habitat and snag availability in the lower Colorado River valley.

Vegetation habitat type*	Snag habitat type				
	Cottonwood	Willow	Honey mesquite	Screwbean mesquite	Snagless
Cottonwood- willow	5**	10	-	-	5
Honey mesquite	-	-	15	-	5
Screwbean mesquite	4	4	-	5	7
Salt cedar (Tamarisk)	-	1	2	-	9
TOTAL	9	15	17	5	26

* From Anderson et al. 1977

** Number of transects

Table 2.--Snag density in the lower Colorado River valley.
Mean $\pm$ SE, N/40 ha.

	Snag habitat types				
	Cottonwood	Willow	Honey mesquite	Screwbean mesquite	Snagless
Number of transects	9	15	17	5	26
Snag species					
Cottonwood	215 $\pm$ 22	-	-	-	-
Willow	104 $\pm$ 16	184 $\pm$ 14	-	-	-
Honey mesquite	-	-	122 $\pm$ 4	-	-
Screwbean mesquite	109 $\pm$ 23	12 $\pm$ 3	2 $\pm$ 0.3	130 $\pm$ 30	-
TOTAL					
DENSITY	428 $\pm$ 32 *	196 $\pm$ 16	123 $\pm$ 4	130 $\pm$ 30	0 $\pm$ 0

* Cottonwood habitat had significantly more snags when compared to honey mesquite alone, screwbean mesquite alone, and all other habitats combined (Dunn's Multiple Comparison values >2.69 , $P<0.05$).

densities were high and unequal; nonparametric analysis revealed that there were more snags in cottonwood habitat than in all other areas combined and more than in honey mesquite or screwbean mesquite habitats alone (Dunn's Multiple Comparison [DMC]; values of 2.99, 2.70, and 2.80, respectively; $P<0.05$ in all cases; Dunn 1964). All other comparisons were not significant.

Seasonal Variation in Bird Densities

Brown-crested Flycatchers (*Myiarchus tyrannulus*) and Ash-throated Flycatchers (*M. cinerascens*) were present in summer only (fig. 1). Individual Ash-throated Flycatchers may be found in winter widely scattered in desert washes and honey mesquite habitats. Northern Flickers (*Colaptes auratus*) were more abundant in winter than in summer, whereas Gila Woodpeckers and Ladder-backed Woodpeckers appeared to be more abundant in summer (fig. 1).

Annual Variation in Bird Densities

There were no significant differences among years in numbers of any of the woodpeckers in summer nor in the Gila Woodpecker (*Melanerpes uropygialis*) in winter (fig. 1, table 3). Ladder-backed Woodpecker (*Picoides scalaris*) numbers were lower in winter 1976-1977 than in 1977-1978 (Dunn's Multiple Comparison, $Z = 2.53$, $P<0.05$). Northern Flickers had highest densities in winter 1978-1979, intermediate in winter 1976-1977, and lowest in winter 1977-1978 (all differences significant, DMC = 2.81 to 7.91, $P<0.05$ in all cases). Brown-crested Flycatcher densities did

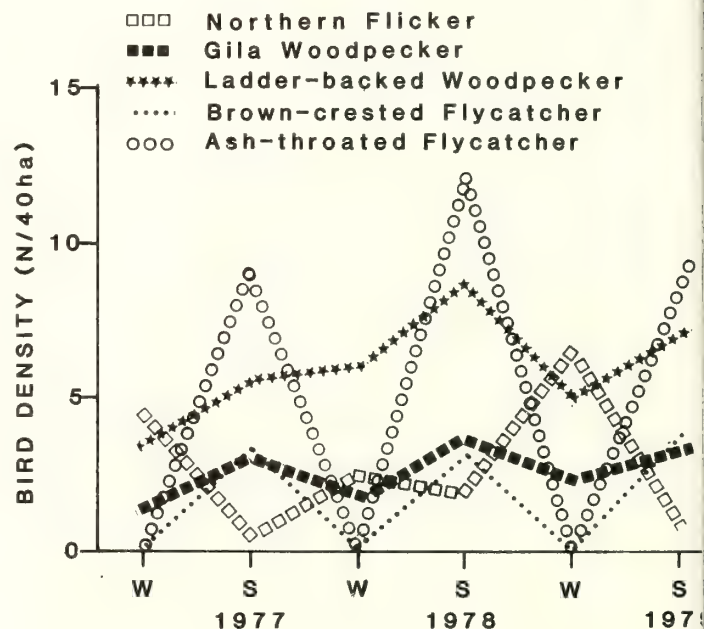


Figure 1.--Seasonal fluctuations in population density of cavity-nesting birds, lower Colorado River valley. Numbers presented are means, all standard errors <0.2 .

Table 3.--Yearly fluctuations of populations of cavity-nesting birds, lower Colorado River valley. -- indicates not present, > indicates population was significantly higher in one year compared to another, ns = nonsignificant. Based on Dunn's Multiple Comparison Test, values >2.69 for significance at $P < 0.05$.

Species	Winter	Summer
Northern Flicker	1978-79>1976-77>1977-78	ns
Gila Woodpecker	ns	ns
Ladder-backed Woodpecker	1977-78>1976-77	ns
Brown-crested Flycatcher	--	ns
Ash-throated Flycatcher	--	1978>1977

not vary significantly; Ash-throated Flycatchers were more abundant in summer 1978 than in summer 1977 (DMC = 2.70, $P < 0.05$).

Habitat Preference

Overall, in 18 of 24 comparisons among snag habitat types (1 per species per season, Dunn's Multiple Comparison, $P < 0.05$), cavity-nesters proved to be more abundant in cottonwood than in other snag habitats (figs. 2-9, tables 4 and 5). In two of the remaining six cases, there was no habitat preference (Gila Woodpecker in winter 1977-78 and in summer 1978). The other four cases are Ladder-backed Woodpecker in winter 1978-1979, and Ash-throated Flycatcher in summer 1977, 1978, and 1979; these are discussed below.

Winter

Cottonwoods were preferred habitat in seven of nine comparisons (table 4). Northern Flickers showed a primary preference for cottonwood and a secondary preference for willow in 1976-1977 (fig. 3). There appeared to be a weak, but not statistically significant, preference for willow in the other two winters. Gila Woodpeckers also showed a preference for cottonwood in 1976-1977 and 1978-1979 winters. The large amount of within-habitat variation in 1977-1978 appeared to cause lack of habitat preference within that period, although the mean density of Gila Woodpeckers in cottonwood habitat was higher than in other habitats (fig. 5). Gila Woodpeckers were uncommon in mesquite and snagless habitats ($N < 2/40$ ha) in all winters. Ladder-backed Woodpeckers preferred cottonwood habitat in the first two winters but not in the winter of 1978-1979 when they were abundant in other habitats. They showed a clear preference for honey and screwbean mesquite habitat over snagless habitat in 1978-1979 (fig. 7).

Summer

In 11 of 15 comparisons, cottonwood was preferred habitat (table 5). However, there was a secondary preference for willow (seven of the above 11 cases) by most species. Northern Flickers preferred cottonwood all three summers and showed a secondary

preference for willow in 1977 and 1979 (fig. 2). This species was seldom seen in mesquite and snagless habitats in all years and was rarely seen in willow in 1979. Gila Woodpeckers showed a different pattern each year, preferring cottonwood primarily and willow secondarily in 1977, showed no preference in 1978, and preferred cottonwood only in 1979. There appeared to be larger population fluctuations in this species than in other species of woodpeckers; however, Gila Woodpeckers were rarely seen in snagless and screwbean mesquite habitats in all three summers. Distribution appeared to be most even across habitats in 1978 (fig. 4). Ladder-backed Woodpeckers preferred cottonwood over other habitats all three years (fig. 6). In 1978, there was a secondary preference for willow; in the other summers, mesquite habitats were preferred over snagless habitats. Brown-crested Flycatchers showed a primary preference for cottonwood and a secondary preference for willow in each summer (fig. 8). This species was almost totally absent from other habitats. Ash-throated Flycatchers showed a different pattern: honey mesquite and willow, and screwbean mesquite in 1977, were preferred over remaining habitats. Ash-throated Flycatchers were present in all habitats, including snagless habitats (fig. 9).

There was no clear-cut relationship between population levels and variation in habitat selection. Secondary cavity-nesters (flycatchers) appeared to be more consistent in habitat selection than were primary cavity-nesters (woodpeckers).

Foraging Behavior of Woodpeckers

Analysis of foraging behavior revealed some differences, despite great disparity in sample sizes among species.

Foraging Method

There were significant differences in foraging methods among woodpeckers (fig. 10, $\chi^2 = 1307.5$, $df = 6$, $P < 0.005$). Ladder-backed Woodpeckers foraged by pecking more than did Gila Woodpeckers or Northern Flickers. Gila Woodpeckers probed and gleaned more often than Ladder-backed Woodpeckers. There was a higher proportion of observations in

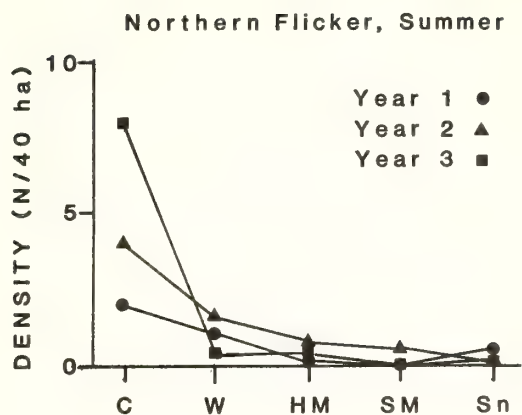


Figure 2.--Habitat selection by Northern Flickers in summer, lower Colorado River valley. C = cottonwood, W = willow, HM = honey mesquite, SM = screwbean mesquite, Sn = snagless. Year 1 = 1977, Year 2 = 1978, Year 3 = 1979.

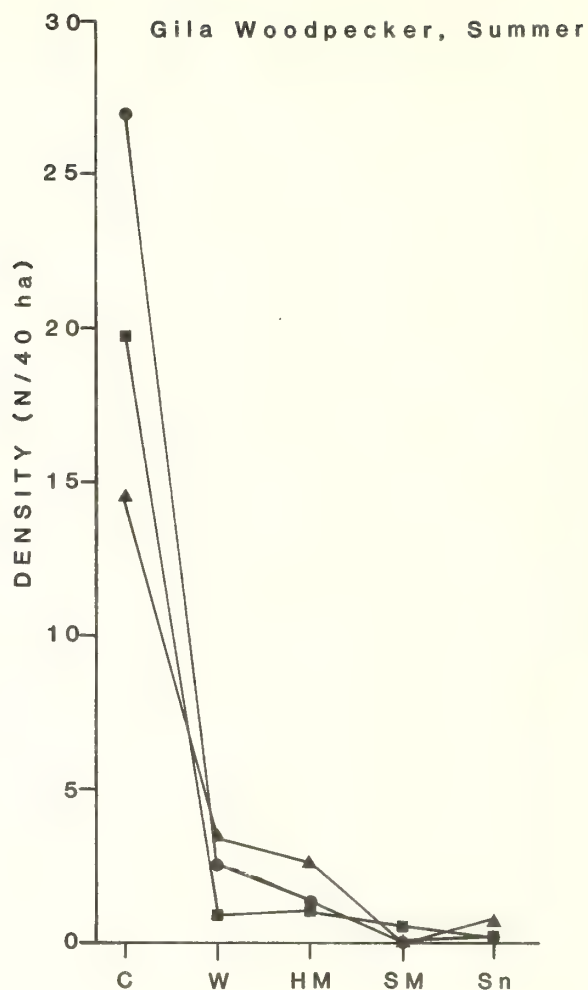


Figure 4.--Habitat selection by Gila Woodpeckers in summer, lower Colorado River valley. Years, abbreviations, and symbols as in figure 2.

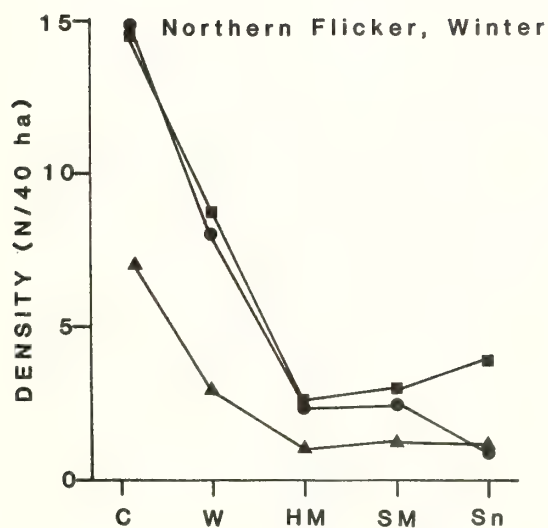


Figure 3.--Habitat selection by Northern Flickers in winter, lower Colorado River valley. Year 1 = 1976-1977, Year 2 = 1977-1978, Year 3 = 1978-1979. Abbreviations and symbols as in figure 2.

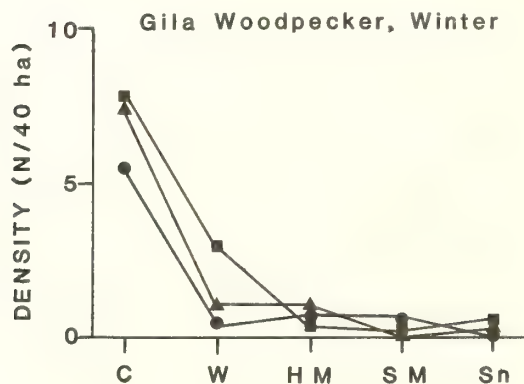


Figure 5.--Habitat selection by Gila Woodpeckers in winter, lower Colorado River valley. Years as in figure 3 and abbreviations and symbols as in figure 2.

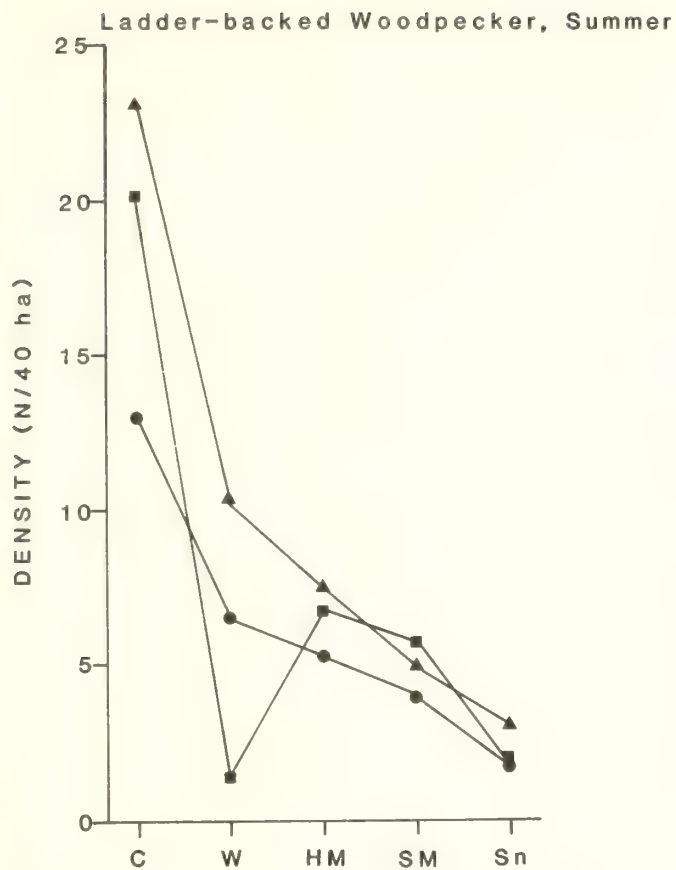


Figure 6.--Habitat selection by Ladder-backed Woodpeckers in summer, lower Colorado River valley. Years, abbreviations, and symbols as in figure 2.

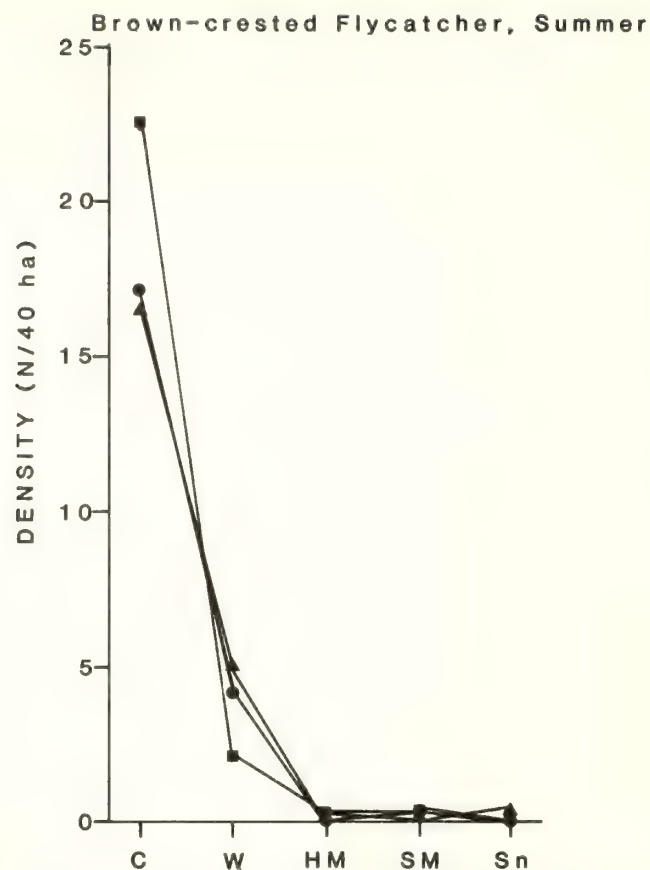


Figure 8.--Habitat selection by Brown-crested Flycatchers in summer, lower Colorado River valley. Years, abbreviations, and symbols as in figure 2.

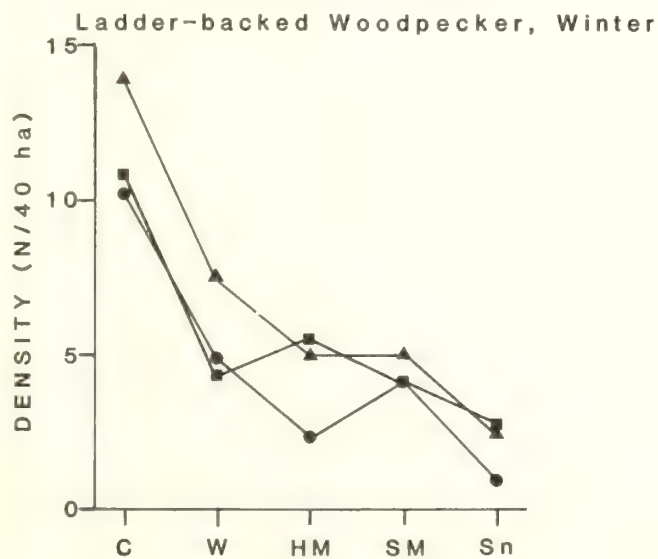


Figure 7.--Habitat selection by Ladder-backed Woodpeckers in winter, lower Colorado River valley. Years as in figure 3 and abbreviations and symbols as in figure 2.

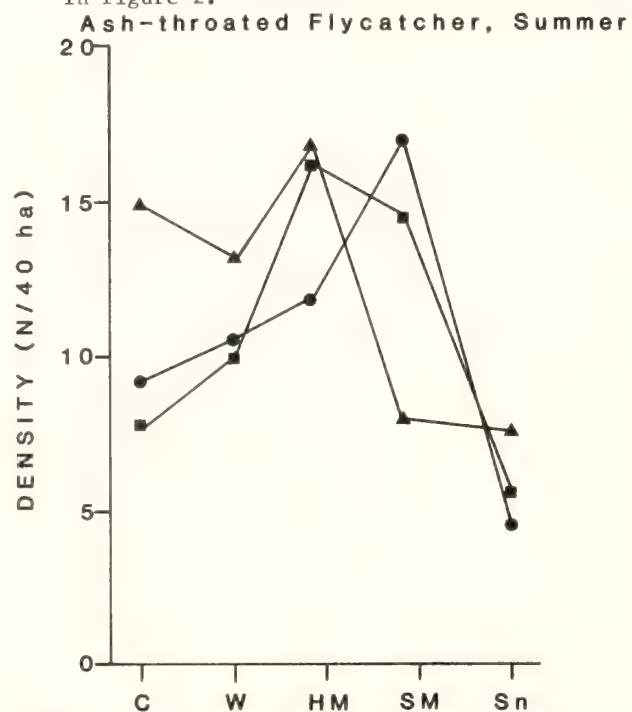


Figure 9.--Habitat selection by Ash-throated Flycatchers in summer, lower Colorado River valley. Years, abbreviations, and symbols as in figure 2.

Table 4.--Habitat selection of three cavity-nesting birds in winter in the lower Colorado River valley. Habitats are listed in order of preference. Snag habitats include: cottonwood, willow, honey mesquite, screwbean mesquite, and snagless. "Others" indicates habitats not previously listed. Kruskal-Wallis nonparametric test used in all cases involved $P < 0.05$.

Bird species	1976-1977	1977-1978	1978-1979
Northern Flicker	Cottonwood Willow Others	Cottonwood Others	Cottonwood Others
Gila Woodpecker	Cottonwood Others	None	Cottonwood Others
Ladder-backed Woodpecker	Cottonwood Others	Cottonwood Others	Honey mesquite and screwbean mesquite Snagless

Table 5.--Habitat selection of cavity-nesting birds in summer in the lower Colorado River valley. Habitats as in table 4.

Bird species	1977	1978	1979
Northern Flicker	Cottonwood Willow Others	Cottonwood Others	Cottonwood Willow Others
Gila Woodpecker	Cottonwood Willow Others	None	Cottonwood Others
Ladder-backed Woodpecker	Cottonwood Others Honey mesquite Snagless	Cottonwood Willow Others	Cottonwood Others Honey mesquite and screwbean mesquite Snagless
Brown-crested Flycatcher	Cottonwood Willow Others	Cottonwood Willow Others	Cottonwood Willow Others
Ash-throated Flycatcher	Honey mesquite, screwbean mesquite, and willow Cottonwood and snagless Others Snagless	Honey mesquite and screwbean mesquite Snagless Honey mesquite and willow Others	Honey mesquite and willow Others Others Snagless

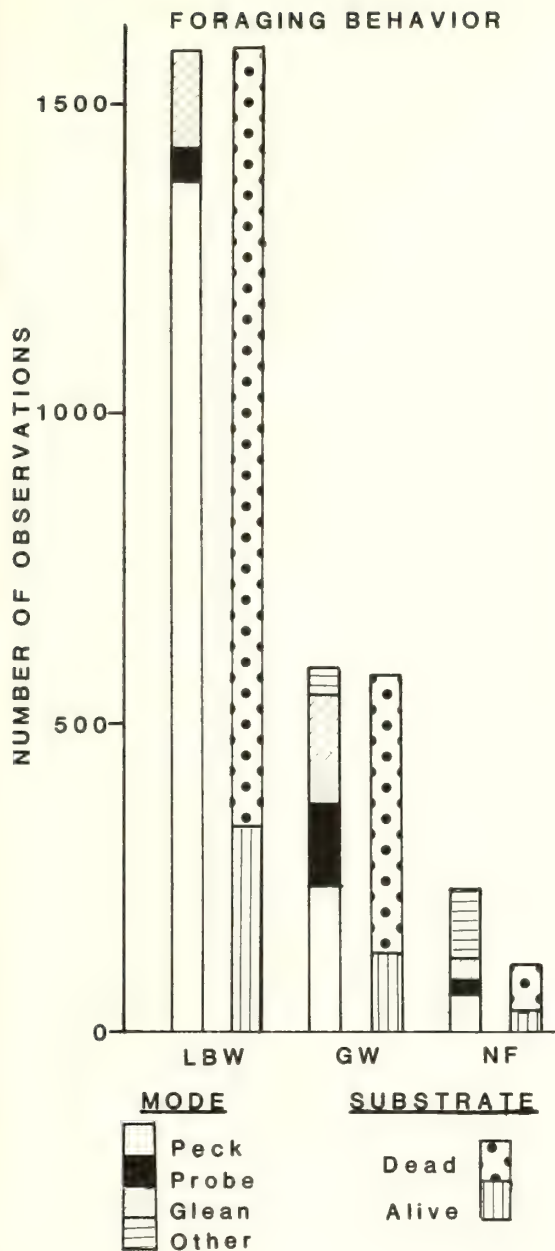


Figure 10.--Foraging behavior of woodpeckers - mode and substrate. LBW = Ladder-backed Woodpecker, GW = Gila Woodpecker, NF = Northern Flicker.

the "other" column for Gila Woodpeckers and Northern Flickers than for Ladder-backed Woodpeckers. Most of the observations in this category represent frugivory (eating mistletoe, *Phoradendron californicum*, berries) by the Gila Woodpecker and ground-foraging by the Northern Flicker.

Foraging Substrate

There were no significant differences among woodpeckers in the proportion of foraging time spent on dead limbs or snags (fig. 10, $\chi^2 = 0.43$, $df = 2$, $P > 0.5$).

Comparison of Snag Usage in Different Habitats

Cottonwood and willow snags were used to the same extent for nesting on the cottonwood-willow study area ($\chi^2 = 1.13$, $df = 1$, $P > 0.25$). Neither snag species had greater than 20% use (fig. 11). Use of cottonwood and willow snags in the cottonwood-willow study area was lower than use of these species in mesquite study areas (cottonwood: $\chi^2 = 13.4$, $df = 1$, $P < 0.005$; willow: $\chi^2 = 24.3$, $df = 1$, $P < 0.005$). Cottonwood and willow combined were used by cavity-nesters to a greater extent than was honey mesquite on the honey mesquite study area ($\chi^2 = 6.8$, $df = 1$, $P < 0.025$) or screwbean mesquite on the screwbean mesquite study area ($\chi^2 = 12.8$, $df = 1$, $P < 0.005$).

There were no areas containing both honey mesquite and screwbean mesquite snags; however, use of honey mesquite was significantly greater than use of screwbean mesquite ($\chi^2 = 5.5$, $df = 1$, $P < 0.025$, fig. 11). Tamarisk (*Tamarix chinensis* and *T. aphylla*) snags were not used at all (45 *T. chinensis* and 11 *T. aphylla* snags on 10 study areas). Ten of 22 telephone poles along a dirt road within a honey mesquite habitat contained cavities. In habitats having both hardwood (mesquite) and softwood (cottonwood, willow, and saguaro, *Carnegiea gigantea*) snags, Ladder-backed Woodpeckers used hardwood snags for cavity excavation to a significantly greater extent than did Northern Flickers and Gila Woodpeckers ($\chi^2 = 24.7$, $df = 2$, $P < 0.001$, table 6).

DISCUSSION

Densities of cavity-nesting species showed a fluctuating seasonal pattern. Densities were higher in the breeding season (spring and summer) than in winter. The Northern Flicker was an exception to this pattern in that there was an influx of *C. a. cafer*, which obscured any seasonal pattern that might have been shown by the resident *C. a. chrysoides* (Phillips et al. 1964). Among nonresident cavity-nesters, Brown-crested Flycatchers winter from Mexico south into South America, whereas Ash-throated Flycatchers winter in most of Mexico and in northern Central America (Lanyon 1960, 1961).

Significant between-year variations in densities of cavity-nesters were limited and can probably be explained on the basis of the winter's severity. The coldest winter during the study period was 1978-1979, when temperatures below freezing were common. Winter 1976-1977 was intermediate, whereas winter 1977-1978 was exceptionally warm and had high rainfall (Meents et al. 1981). Northern Flicker abundance was proportional to winter severity, probably due to a greater influx of migrant flickers from other areas. Trends in other woodpecker populations were similar, with greatest reductions in numbers occurring in the harsh winter, although this difference was not significant.

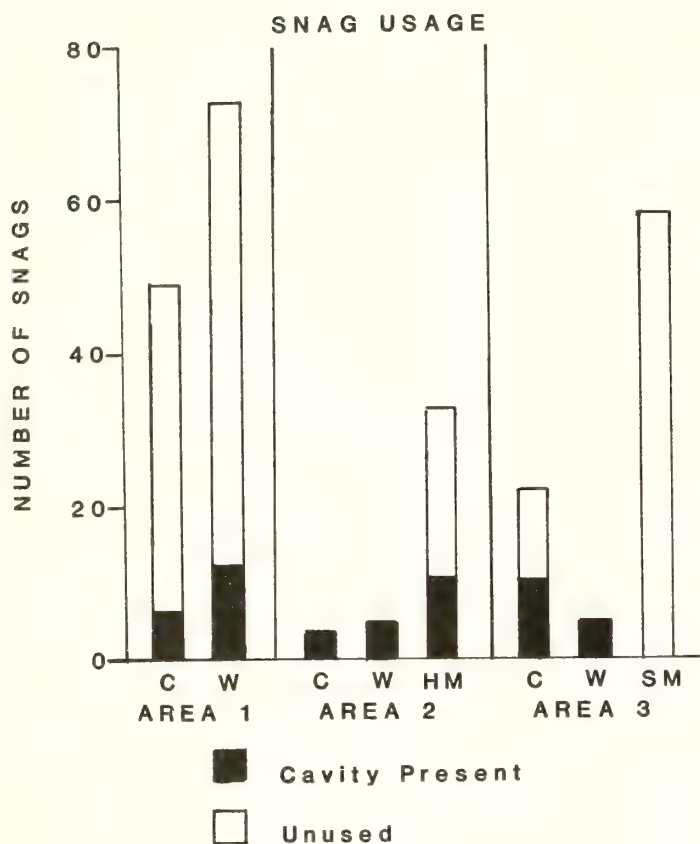


Figure 11.--Snag usage by cavity-nesting birds in different vegetation habitats, lower Colorado River valley. Abbreviations as in figure 2. Area 1 = cottonwood-willow vegetation, Area 2 = honey mesquite vegetation, Area 3 = screwbean mesquite vegetation.

Table 6.--Nest-site selection by woodpeckers in the lower Colorado River valley.

Bird species	Snag type	
	Softwood ^a	Hardwood ^b
Northern Flicker	12 ^c	--
Gila Woodpecker	9	3
Ladder-backed Woodpecker	--	10

^aCottonwood, willow, and saguaro.

^bHoney mesquite and screwbean mesquite.

^cFigures indicate number of active nests or roosts.

Habitat Preference

Overall preference for cottonwood snag habitat was highly significant; preference for willow was only sometimes significant. This trend can be explained by a combination of snag use (fig. 11) and snag abundance data (table 2). In cottonwood, the greater abundance and diversity of snag species and presence of softwood species appears to explain why four of five cavity-nesting bird species preferred this habitat. Presumably, many of these snags provided potential nest sites. In willow habitat, the presence of willow snags, another softwood, probably explains the secondary preference for this habitat. Availability of roost holes in winter may be as important as nest sites in summer for woodpeckers (Baker 1971). Ladder-backed Woodpeckers appear to have been less dependent on softwood trees than were Gila Woodpeckers or Northern Flickers; hence there was a weak preference by Ladder-backed Woodpeckers for mesquite habitat over snagless habitat. Gila Woodpeckers and Northern Flickers were almost absent from mesquite in summer. The fact that Northern Flickers were present in mesquite areas in winter may be due to use of noncavity roost sites for this species (Bent 1939).

Morphological adaptations in woodpecker species may explain both habitat preference and foraging method. Ladder-backed Woodpeckers, because of structural modifications of skull, vertebrae, and ribs, are best adapted for excavating hardwood (Kirby 1980). This species feeds primarily by pecking, and it can excavate nest sites in hard-wooded mesquite trees. Northern Flickers and Gila Woodpeckers are less well adapted for excavating nest holes in hardwoods. This may account for their greater use of nonexcavating foraging modes, their dependence on softwood snags for cavity excavation, and their less frequent occurrence in mesquite habitats. The occurrence of Gila Woodpeckers and Northern Flickers seems to be dependent on nest site availability, since they seem more adaptable in foraging methods.

The species most restricted to cottonwood and willow snag habitats was the Brown-crested Flycatcher. This can best be explained by patterns of nest site availability, as this relatively large secondary cavity-nester is dependent on the presence of large cavities for nesting. There appear to be few large natural cavities in any of the habitats in the lower Colorado River valley. Brown-crested Flycatchers have been observed foraging in honey mesquite, screwbean mesquite, and salt cedar habitats surrounding lone cottonwood or willow snags in which woodpecker cavities were present, in five of the transects classified here as cottonwood or willow.

Habitat preference of Ash-throated Flycatchers is more difficult to explain. The abundance of this species does not appear to be positively correlated with any primary or secondary cavity-nesting species. The only similarity in habitat selection to other cavity-nesting bird species is in its avoidance of snagless habitats. Ash-throated Flycatchers appear to be as common in cottonwood snag habitat as primary cavity-nesters, but the

much greater abundance of Ash-throated Flycatchers in mesquite and willow snag habitats suggests that this species is not dependent on woodpeckers for nest cavities.

Habitat selection in Ash-throated Flycatchers may be based on vegetational or structural preference. This species shows preference for vegetation of moderate height (3.0-4.5 m; Anderson and Ohmart unpubl. data) and is often found in mesquite habitat (Phillips et al. 1964). The lack of dependence on woodpeckers is shown by its use of natural cavities (Bent 1942, pers. obs.) as well as woodpecker cavities.

There appears to be an inverse relationship between abundance patterns of Brown-crested Flycatchers and Ash-throated Flycatchers in the lower Colorado River valley. This could be attributed to competitive exclusion (Cody 1974), as diets and foraging mode are very similar (Rosenberg et al. 1982). However, nest sites are partitioned on the basis of size in these two species (Brush 1981), and interspecific territoriality away from the nest site has not been observed. Size difference between the species and a superabundant food resource may aid in avoidance of competition. That size is important is supported by anecdotal evidence of interspecific territorial behavior in the limited overlap between Brown-crested Flycatchers and the similar-sized Great Crested Flycatcher, Myiarchus crinitus (Oberholser 1974).

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Breeding Bird Use of Flooded Dead Trees in Rathbun Reservoir, Iowa¹

Teresa L. Burns² and Robert B. Dahlgren³

Abstract.--Birds using flooded dead trees in a large flood-control reservoir were compared with those using bottom-land timber areas upstream. The flooded dead trees had a lower avian density and less diversity of species than unflooded areas, but a greater number of secondary cavity-nesting species. Nests of three primary cavity-nesting, six secondary cavity-nesting, and three open-nesting species were found in the flooded trees. Flooded trees add significantly to the nesting bird population of the reservoir.

INTRODUCTION

With the construction of a large flood-control reservoir, thousands of acres of riparian habitat are inundated. Included in this loss is bottom-land forest which may contain higher densities and diversities of birds than do the adjacent uplands (Odum 1978). It is very costly to remove the trees, and the current Corps of Engineers' policy is to remove as little timber from the reservoir as possible, clearing only for the dam site and for boating routes.⁴ The remaining trees soon die after flooding, providing a unique habitat for cavity-dependent species of wildlife. It is estimated that many of the dead trees remain standing for about 25-30 years.⁵ Yeager (1955) found that the number of woodpeckers increased in bottomland areas along the Mississippi River in Illinois as the result of flooding and killing of bottomland trees. There also has been some previous work done on flooded dead trees used by ducks in shallow reservoirs (Cowardin 1969) and by woodpeckers in beaver ponds during winter (Hair

et al. 1978, Lochmiller 1979). The purpose of this paper is to compare the bird use of dead trees and of bottomland timber.

STUDY AREA AND METHODS

Rathbun Reservoir, located on the Chariton River in south-central Iowa, was chosen as the study site. Flooded dead trees, located only in the upper reaches of the reservoir, occupy about 10% (420 ha) of the reservoir's 4450 ha of surface area at the normal pool level of 904 feet above mean sea level (msl). The water level remained between 914 and 915 msl for most of the study, but in July 1982, it rose to the highest level (924 msl) ever recorded. There are two branches in the upper reaches of the reservoir: the North Fork, containing 80% of the flooded trees, and the South Fork, which contains the remaining 20%. Most of the land surrounding these two branches is managed for wildlife by the Iowa Conservation Commission. The reservoir was flooded in 1969, and all trees below 907 msl were killed by 1971.⁶ Because of the turbidity of the water and the widely fluctuating water levels, there was no aquatic vegetation found around any of the flooded trees.

In addition to the flooded trees, bottomland timber 10-15 km upstream from the plots in the flooded trees also was censused. The bottomland areas chosen were all above the previous reservoir high of 918 msl and were not subject to the water level changes in the reservoir. The dominant tree species on the sample plots include silver maple

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²Teresa L. Burns is a graduate student at Iowa State University, Ames, Iowa.

³Robert B. Dahlgren is Unit Leader of the Iowa Cooperative Wildlife Research Unit, Ames, Iowa. Agencies cooperating in the Unit are U.S. Fish and Wildlife Service, Iowa Conservation Commission, Iowa State University, and Wildlife Management Institute.

⁴Bryan, K. 1983. Personal conversation. U.S. Army Corps of Engineers, St. Louis, Mo.

⁵Thompson, D. Q. 1983. Personal conversation. U.S. Fish and Wildlife Service, Ft. Collins, Col.

⁶Brunk, E. L., A. D. Allman, and G. P. Delinger. 1975. Mortality of trees caused by flooding during the growing season at two midwest reservoirs. Unpublished report. Missouri Dept. of Conservation, Jefferson City, Mo.

(*Acer saccharinum*), American elm (*Ulmus americana*), red elm (*Ulmus rubra*), hackberry (*Celtis occidentalis*), and green ash (*Fraxinus pennsylvanica*). Other tree species include pin oak (*Quercus palustris*), swamp white oak (*Quercus bicolor*), bitternut hickory (*Carya cordiformis*), shellbark hickory (*Carya laciniosis*), mulberry (*Morus rubra*), and hawthorn (*Crataegus* spp.).

Birds were censused in each of the areas by using a circular-plot method. All birds seen or heard within a 50-m radius in 10 minutes were recorded. Flying birds such as swallows that were foraging over the plot were included in the census, but aquatic birds resting on the water were not. Counts were begun in late May 1982 and continued through early July until all plots were censused four times. Forty plots were established, 20 each in the bottomland timber and flooded trees, with 10 plots on the South Fork and 30 on the North Fork of the river. Plots were censused in early morning and were systematically rotated as to the time when counts were made. Birds were censused from a canoe in the flooded trees. The flooded trees also were searched for evidence of nests. Nests that could not be viewed from the canoe were verified by observing at least three feedings of nestlings or by hearing nestlings in the nest.

Species diversity was calculated by using the Shannon formula ($-\sum p \log p$). Species richness is the average number of species per plot. A *t*-test was used to test for differences between means.

Relative numerical component (RN) was calculated as the number of bird observations divided

by the number of observations for the most abundant species. Relative spatial component (RS) is the number of different plots on which the bird was observed divided by the total number of plots. Important value (IV) is equal to RN + RS.

RESULTS AND DISCUSSION

Species diversity and species richness were greater in the bottomland timber than in the flooded trees (table 1). A total of 15 species were observed in the flooded trees during censusing as compared with 28 in the bottomland timber. Species diversity usually is associated with increasing complexity of the vegetation structure in a habitat (MacArthur 1964); however, dead trees (Balda 1975) and water (Karr 1968) may also increase diversity.

Table 1. Mean bird species diversity (H') and species richness (S) for census plots in flooded dead trees and bottomland timber areas during summer 1982 at Rathbun Wildlife Unit, Iowa. (Means were different; $P < 0.0001$)

	H'		S	
	$\bar{x}$	SE	$\bar{x}$	SE
Bottomland timber ($N = 20$)	1.97	0.05	10.25	0.56
Flooded timber ($N = 20$)	1.32	0.04	5.45	0.31

Table 2. Relative numbers, relative spatial components, and importance values by habitat for cavity-nesting birds during summer 1982 at Rathbun Wildlife Unit, Iowa. The mean numbers of birds per plot per census are given in parentheses.

Flooded dead trees				Bottomland timber			
Species	RN	RS	IV	Species	RN	RS	IV
European starling (3.78) (<i>Sturnus vulgaris</i>)	1.00	1.00	2.00	Red-headed woodpecker(0.88) (<i>Melanerpes erythrocephalus</i>)	1.00	0.95	1.95
Tree swallow(2.41) (<i>Iridoprocne bicolor</i>)	0.64	1.00	1.64	House wren(0.75) (<i>Troglodytes aedon</i>)	0.86	1.00	1.86
House sparrow(1.90) (<i>Passer domesticus</i>)	0.50	0.90	1.40	Black-capped chickadee(0.24) (<i>Parus atricapillus</i>)	0.27	0.65	0.92
Red-headed woodpecker(0.69) (<i>Melanerpes erythrocephalus</i>)	0.18	0.85	1.03	Great crested flycatcher(0.16) (<i>Myiarchus crinitus</i>)	0.18	0.40	0.58
Northern flicker(0.24) (<i>Colaptes auratus</i>)	0.06	0.55	0.61	Northern flicker(0.10) (<i>Colaptes auratus</i>)	0.11	0.30	0.41
Common grackle(0.13) (<i>Quiscalus quiscula</i>)	0.03	0.40	0.43	Barred owl(0.03) (<i>Strix varia</i>)	0.03	0.10	0.13
Wood duck(0.04) (<i>Aix sponsa</i>)	0.01	0.05	0.06	White-breasted nuthatch(0.03) (<i>Sitta carolinensis</i>)	0.03	0.10	0.13
House wren(0.01) (<i>Troglodytes aedon</i>)	< 0.01	0.05	0.05	Red-bellied woodpecker(0.03) (<i>Melanerpes carolinus</i>)	0.03	0.10	0.13
Red-bellied woodpecker ¹ (0) (<i>Melanerpes carolinus</i>)	0	0	0	Hairy woodpecker(0.01) (<i>Picoides villosus</i>)	0.01	0.05	0.06
Great crested flycatcher ¹ (0) (<i>Myiarchus crinitus</i>)	0	0	0	Downy woodpecker(0.01) (<i>Picoides pubescens</i>)	0.01	0.05	0.06

¹Species was not observed during censusing but their nests were found in flooded dead trees.

Lack of foliage probably is the major reason for less species diversity in the flooded trees.

In comparing bird species found in flooded trees with those in bottomland timber, birds were divided into two groups based upon their nesting habit, primary or secondary cavity-nesting. The number of secondary cavity-nesting species was greater ($P < 0.0001$) in the flooded trees ($\bar{x} = 32.0$) than in the bottomland timber ($\bar{x} = 4.8$). Starlings, tree swallows, and house sparrows had the highest importance values in the flooded trees (table 2), making up 88% of birds observed there. None of these species was observed in the bottomland timber. The secondary cavity-nesting species that are found in both areas are the great crested flycatcher and house wren; however, both had much higher importance values in the bottomland timber (table 2).

Although there were more secondary cavity-nesting species in the flooded trees, the number of primary cavity-nesting birds ($\bar{x} = 3.6$ for flooded trees, $x = 4.0$ for bottomland timber) did not differ between the areas ($P = 0.66$), though there were more birds seen in the bottomland timber. The red-headed woodpecker had the highest importance value for primary cavity nesters in both areas (table 2), followed by the northern flicker and red-bellied woodpecker. Yeager (1955) found red-headed woodpeckers to be the most numerous woodpecker 1 to 8 years after flooding at a dam built near the confluence of the Illinois and Mississippi rivers. Lochmiller (1979) also found that the red-headed woodpecker was the most common of seven woodpeckers using flooded dead trees in beaver ponds in Georgia during winter. Downy and hairy woodpeckers were not observed in the flooded trees at all and only rarely in the bottomland timber at Rathbun.

Nests were found of all species observed during the censusing in the flooded trees except those of chimney swifts (*Chaetura pelagica*), barn swallows (*Hirundo rustica*), American crows (*Corvus brachyrhynchos*), blue jays (*Cyanocitta cristata*), and red-winged blackbirds (*Agelaius phoeniceus*). These species used the flooded trees mainly as perch sites and for aerial foraging for insects. In contrast, all the birds that nested in the flooded trees were seen flying into adjacent upland woodlands, row crops, and pastures to forage. Such foraging must be necessary to support the large numbers of cavity-nesting birds in the flooded trees.

Nests of three open-nesting species were found in the flooded trees including those of red-tailed hawk (*Buteo jamaicensis*) and eastern kingbird (*Tyrannus tyrannus*) in 1982 and, in spring of 1983, a mallard (*Anas platyrhynchos*). There is a great blue heron (*Ardea herodias*) colony with about 20 nests in the flooded trees as well as a

smaller colony with 6 nests located in live bottomland trees near the gradient between the reservoir and river. Two of the open-nesting species, red-tailed hawk and great blue heron, used snags with limbs to support their nests, whereas eastern kingbird and mallard nests were all on stumps.

CONCLUSIONS

Although this study was conducted in the summer, flooded and downed trees were used by birds throughout the year. Migrating ducks often used fallen trees as resting areas, and raptors used dead trees as perch sites. Although flooded trees cannot mitigate the loss of the diversity and richness of bird species in bottomland timber, their presence can increase the number of birds nesting in the area for about 30 years. The low species diversity value in the flooded trees is greater than the value that would have occurred if the trees had been cleared.

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Nestholes in Live and Dead Aspen¹

Barbara L. Winternitz and Helen Cahn²

Abstract.--A comparison of three studies in two Colorado montane aspen stands indicated that almost 40% of birds breeding in aspen used nestholes. Over 50% of the nesthole trees were infected by *Fomes igniarius* conks. Nesthole trees were larger than the other aspen, and estimated to average well over 100 years in age.

INTRODUCTION

Almost half of the birds breeding in Colorado montane forests use nestholes to protect their eggs and young, and many of the species show a preference for Quaking Aspen, *Populus tremuloides* Michx., vegetation and nestholes drilled in aspen.

Here we want to present data gathered in three studies of two areas in Colorado aspen, to show the interesting relationships found between the birds, their nestholes, the aspen and other vegetation parameters.

STUDY AREAS AND METHODS

A first study site was in Crow Gulch, on Pikes Peak, near Colorado Springs, CO. A twenty hectare (ha.) grid was studied in a five year breeding bird spot-map census from 1967 to 1971. Elevation varied from 2658 to 2762 meters (m). The balanced montane vegetation there included Douglas Fir (*Pseudotsuga menziesii*), pines (*Pinus ponderosa* and *P. flexilis*) and spruce (*Picea* spp.) as well as riparian aspen growths. Most of the breeding bird species here showed a preference for aspen (Winternitz, 1976). In 1977 and 1978, measurements of the nesthole trees and mapping of Heartrot Fungus (*Fomes igniarius*) were completed.

The second study site was on Black Mountain, near Fairplay, Colorado, at a slightly higher elevation near 3,000 m. The 24 ha. grid supported a stable aspen vegetation present in all age classes. Few conifers were found, and no open water was nearby. The constant slope to the west minimized topographic and climate differences. Figure 1 depicts the site, and shows the separation of the aspen into a lower and upper grove by the presence of a meadow alleyway.

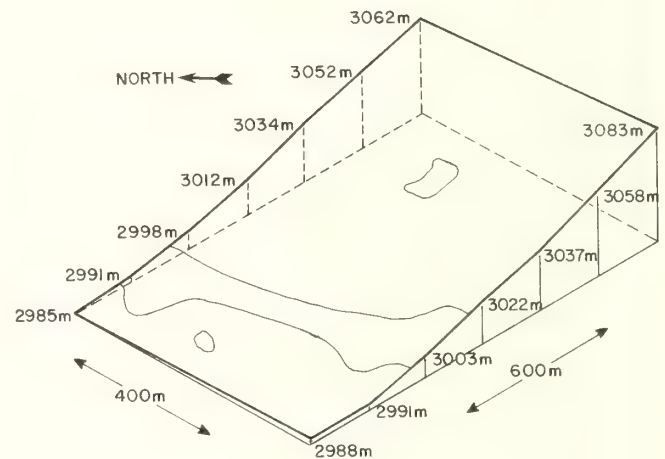


Figure 1. Model of the Black Mountain study area.

A five year breeding bird census was made from 1978 to 1982, using the spot-map method (Williams, 1936). During these five years the location of all nestholes found was recorded, and measurements taken of the trees, the holes, and *Fomes* infection. In Hectare II, all trees were inspected for the fungus, and measured and marked if infected. In 1981 and 1982, the vegetation of the entire site was sampled using a combination of the point-quarter method and Daubenmire's Nested Boxes technique (Daubenmire, 1968).

In 1982, 47 individual aspens were core-sampled to determine the relationship between DBH (diameter breast high) and age of the tree. Trees were selected to represent three elevational divisions of the area, the upper upper grove (3034-3062 m. high), the lower upper grove (2998-3034 m.), and the lower grove (2983-2991 m.). The trees were chosen randomly throughout each division, and the DBH of the sampled trees was comparable to that of healthy trees sampled by the

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²Barbara L. Winternitz, Assistant Professor of Biology, The Colorado College, Colorado Springs, CO 80903, and Helen Cahn, The Biology Department, The Colorado College, Colorado Springs, CO 80903.

methods listed above, except that larger trees were more successfully cored than smaller ones, so a slight advantage was given to the larger aspen.

DBH was measured with a tree tape, and an increment borer was used 1 foot from the ground on the tree's south side to extract a core sample (after Campbell, 1981). Height of the tree and canopy dimensions were measured with a clinometer. Core samples were soaked in a 75:24:1 by weight solution of methanol, water, and laboratory detergent for 24 hours, and then shaved to display a transverse view of the rings. Rings were counted and one year added to the count, the average amount of time it takes aspen to grow one foot (Campbell, 1981). Out of 47 trees sampled, 40 were successfully aged. Even the initial stages of *Fomes* infection made reading of the ring count difficult, so the correlation between age and DBH is applicable only to healthy live trees.

The third study reported here was performed by Anthony Ham in the vicinity of both of the above sites. After helping to identify the nestholes in the two grid areas, he measured other nesthole trees nearby (Ham, 1978).

RESULTS

The species and numbers of birds nesting in holes at Black Mountain are emphasized here, as those in Crow Gulch could utilize other coniferous vegetation as well as the aspen. Comparison of the species in the two sites is shown in Table 1.

Table 1. Primary and Secondary Cavity Nesting Birds.

Species	Density/ Black Mt. Av. prs/yr	Presence Crow Gulch
Primary Cavity Nesters:		
Hairy Woodpecker, <i>Picoides villosus</i>	2.0	present
Downy Woodpecker, <i>Picoides pubescens</i>	1.2	present
Yellow-bellied Sapsucker, <i>Sphyrapicus varius</i>	1.5	Williamson's Sapsucker, <i>S. thyroideus</i>
Northern Flicker, <i>Colaptes auratus</i>	2.0	present
Secondary Cavity Nesters:		
White-breasted Nuthatch, <i>Sitta carolinensis</i>	2.2	present
Red-breasted Nuthatch, <i>Sitta canadensis</i>	0.8	present
Mountain Chickadee, <i>Parus gambeli</i>	8.0	present
Black-caped Chickadee, <i>Parus atricapillus</i>	0.3	present
House Wren, <i>Troglodytes aedon</i>	7.0	present

Table 1, cont.

Species	Density/ Black Mt. Av. prs/yr	Presence Crow Gulch
Western Flycatcher, <i>Empidonax difficilis</i>	1.2	present
Tree Swallow, <i>Tachycineta bicolor</i>	6.2	Violet-green Swallow, <i>T. thalassina</i>
Mountain Bluebird, <i>Sialia currucoides</i>	5.6	Western Bluebird, <i>Sialia mexicana</i>

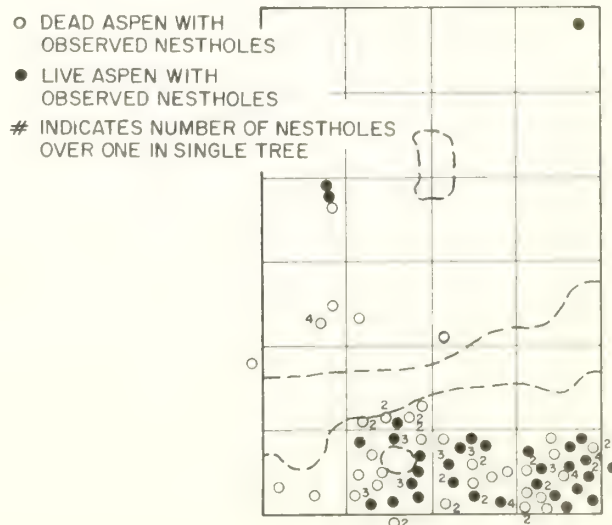
At Black Mountain, the nesting categories were:

%	By numbers	By biomass
1 ^o	7%	20%
2 ^o	32%	18%
	39%	38%

Either way you look at it, 40% of the nesting birds used holes in which to nest.

Nestholes

Nestholes discovered at Black Mountain are presented in Figure 2. Obviously they were evenly distributed between live and dead aspen, and were most common in the lower aspen grove.



A tabular analysis of nesthole measurements in the three aspen studies is seen in Table 2.

Table 2. Nesthole Measurements in the three studies.

Measurement	Crow Gulch	Black Mountain	Ham Study
# aspen trees with holes	32	67	10
# nestholes	37	106	18
% <i>Fomes</i> infected	62%	55%	--
av. DBH of tree	19.72cm	29.22	26.4
range DBH	(8.8-30.7)	(17.8-34.9)	(24.6-30.7)
av. height of hole	4.21m	3.96m	3.43m
range of height	(1.2-10m)	(1.2-9.1m)	(1.4-5.1m)

Figure 3 shows the orientation of nestholes at both Crow Gulch and Black Mountain.

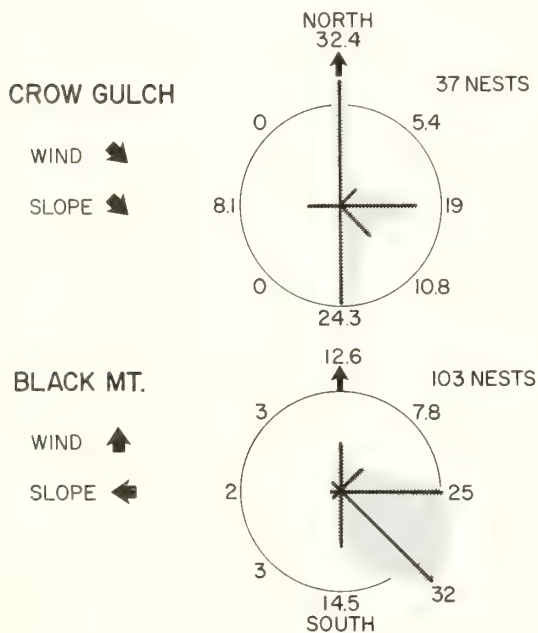


Figure 3. Orientation of bird nestholes in aspen.

At Crow Gulch the strongest winds came from the north and northwest, though ridges protected the study site from them. At Black Mountain, 72% of the winds during June and July came from the southeast, south and southwest, as did the strongest wind--30 mph (U.S. For. Service, 1982).

Table 3. Relative sizes of Black Mountain nestholes.

Round holes		Oblong holes	
2.54cm	8	2.54 x 3.8cm	1
3.17	1	3.17 x 3.8	1
3.8	13	3.8 x 5.1	9
5.1	7	3.8 x 6.3	1
6.3	3	5.1 x 7.6	1
7.6	7	7.6 x 8.9	3

Vegetation Parameters

Age-DBH Correlation for Aspen

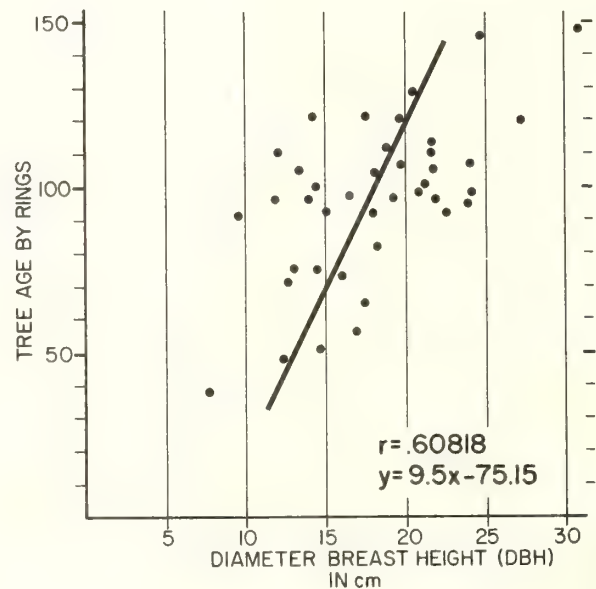


Figure 4. Aspen DBH and age correlated.

In Figure 4, the correlation coefficient, $r = +.60818$, tests to be a highly significant relationship ($p < .01$).

Fomes Infection

In Hectare II, where all the aspen trees were counted and measured, 11% of 1915 trees were found to be visibly infected by the fungus.

The incidence of *Fomes* in all 24 has. varied from 0 to 17.75%, and showed a highly significant difference between hectares.

Figure 5 shows the relationship between percent fungus infection and nesthole numbers.

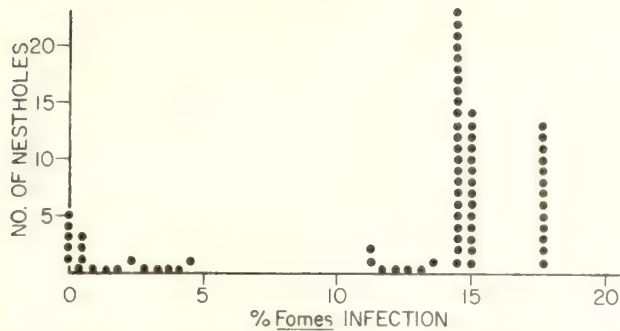


Figure 5. *Fomes* incidence and nesthole numbers.

A correlation coefficient of $R = +.54653$ indicates a significant relationship ($p < .02$).

DISCUSSION

Many Colorado aspen groves are seral stands, subject to future replacement by coniferous trees. In Crow Gulch the riparian nature of the aspen, and the presence of young conifers in the understory, made it difficult to judge the permanence of aspen there.

At Black Mountain, the presence of aspen in all age classes (to 146 years!) and the lack of healthy young conifers, indicates it is a stable aspen stand, as described by Marr, 1967.

The clumping of Black Mountain nestholes in the lower aspen grove (Figure 2) showed the primary cavity nesters were attracted to that area for hole-drilling for some reason. It was not the larger size of the trees, for DBH measurements do not vary significantly from hectare to hectare. It may be related to edge effect (more edge in the lower grove) and/or aspen density (lower tree density in the lower grove). Certainly it is related to Heartrot Fungus infection level (Figure 5). The strong correlation shown between nesthole number and percent infection of *Fomes* leads one to wonder why 60% or less of the nesthole trees showed visible infection. The reason for this may be the presence of less detectable heartrots, such as *Cryptochaete polygonia* (Davidson et al, 1959) and said by them to be responsible for nearly 10% of aspen rot. This fungus is also referred to as *Peniophora polygonia* (Hinds and Wengert, 1977) and said to cause over 14% of aspen rot in their study. Perhaps the woodpeckers can identify this heartrot better than we can.

The relationship of DBH, age of tree, and fungus infection is somewhat less clear, due to our inability to read core rings in infected trees. We found in our core analysis that the trees in the lower grove were younger (av. age 96.7 yrs) and bigger in DBH (19.6 cm av.). In contrast, the upper grove trees averaged 101 years in age, and showed a diminution in DBH as one went upslope (18.11 cm to 16.56 cm). There was a stronger correlation of age and DBH in the lower grove ($r = +.768$). The weakest correlation of age and DBH was found in the upper upper grove, $r = +.5588$.

However, we do not know what effect the fungus has on the tree DBH. Perhaps *Fomes* infection increases tree DBH and therefore our estimate is too high. Using this correlation method in the groves, the average age of a nesthole tree was estimated to be over 170 years old.

Inspection of the various nesthole measurements (Table 2 and Figure 3) showed little variability in average DBH of nesthole trees or the average height of a nesthole. Much more variability was shown in the orientation of nestholes, with more Crow Gulch nestholes facing north, then south and east, while Black Mountain holes showed a strong south and east orientation. It appeared nesthole openings are oriented toward the sun rather than away from the wind. But the positioning of hole openings to all directions at Black Mountain indicated a degree of individual choice as to view.

Hole sizes, Table 3, illustrate a wide range of shape and diameters. Harrison, 1979, typified:

- Downy Woodpecker holes as 3.2 cm in a perfect circle, analogous to the smaller round holes (11 in number)
- Hairy Woodpecker holes as 5.1 x 6.3 cm oblong (12 in number at Black Mountain)
- Flicker holes as over 7 cm round or oblong (12 in number at Black Mountain)
- Yellow-bellied Sapsucker holes as 3.8 cm and round (13 at Black Mountain)

The relative numbers of woodpecker species (Table 1) and such sized nestholes are equitable--but who drilled the 9 holes 3.8 x 5.1 cm in oblong shape?

SUMMARY

1. The aspen at Black Mountain form a stable vegetation community.
2. More nestholes are drilled by birds in the lower grove due to:
 - a. higher heartrot infection
 - b. perhaps due to lower tree density and/or greater proximity to edge.
3. The lower grove was slightly younger in age (av. 97 yrs) and bigger in girth than the upper groves.
4. Nestholes vary little in average height above the ground but greatly in orientation toward the sun. Wind does not seem to be as strong a factor as sunlight in their placement.

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Snag Density and Utilization by Wildlife in the Upper Piedmont of South Carolina¹

D. Breck Carmichael, Jr. and David C. Guynn, Jr.²

Abstract.--Snag densities were estimated for major forest types on the Clemson Experimental Forest, in the upper Piedmont of South Carolina. Two-hundred 0.1-ha plots were established in various aged stands of cove hardwood, upland hardwood, pine-hardwood, and pine plantations. Climable snags containing cavities were inspected to determine use by wildlife during warm months (May-September) and again during cold months (November-March). Mean snag densities were 50.3 snags per ha for upland hardwoods, 37.3 snags per ha for cove hardwoods, 31.2 snags per ha for pine-hardwoods, and 21.3 snags per ha for pine plantations. Cavities occurred in only 8.8% of all snags tallied. Preliminary results indicate that more than 35% of snags with cavities were utilized by southern flying squirrels (Glaucomys volans).

INTRODUCTION

In most natural communities, nongame species constitute the greatest portion of vertebrate species and biomass; furthermore, they are critical to the functioning of the ecosystem (Bury et al. 1980). Wildlife researchers and managers are now aware of the importance of standing dead trees, or snags, as habitats for many of these species. Activities such as bird watching and wildlife photography have become popular (More 1979), with annual expenditures totalling in the millions of dollars in the United States (DeGraaf and Payne 1975). Also, many species of snag-dependent wildlife are insectivorous and help prevent insect populations from reaching epidemic levels (Beebe 1974).

Information on snags and snag-dependent species is lacking in the Southeast. Extensive studies have been carried out on the endangered red-cockaded woodpecker (Picoides borealis), but this species requires live southern pines (Pinus spp.) for cavity construction. All other southern woodpeckers utilize snags for cavity construction,

and a large number of secondary cavity-nesters use these cavities. Some 38 species of birds that breed and/or winter in upper South Carolina are known to utilize snags (Legrand and Hamel 1980). Several mammalian species nest, feed, or hibernate in snags; and amphibians and reptiles may even use snags (McComb and Noble 1981). We initiated a study in 1981 to estimate snag densities in 4 major forest types in the upper Piedmont of South Carolina and to determine the diversity of wildlife species utilizing snags within these forest types.

STUDY AREA

The study was conducted on the 7,024 ha Clemson University Experimental Forest, in the upper Piedmont of South Carolina. The tract was obtained between 1934 and 1939 from private owners by the U. S. Department of Agriculture. More than 100 years of clearing, burning, row cropping and abandonment had turned the area into severely eroded red clay hills and gullies. The scattered woodlands present were mostly rough pines and low quality hardwoods. Federal work programs helped initiate the reforestation of the area, and in 1954 the land was deeded to Clemson University. An intensive forest management program has restored the Clemson Forest to a productive state (Warner et al. 1973).

All study plots were established on the "North Forest," maintained primarily for research, teaching, and recreation. The terrain is slightly

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²D. Breck Carmichael Jr. and David C. Guynn, Jr. are, respectively, Graduate Research Assistant and Associate Professor, Department of Forestry, Clemson University, Clemson, S.C.

rolling to hilly, typical of the upper Piedmont. Stands ranged in size from less than 0.5 ha to greater than 10 ha, and all ages from seedlings to mature sawtimber were present.

METHODS

Four stands in each of the 10 following forest types were located on the study area: pine-hardwood - 20 to 30 years, pine-hardwood - 30 to 50 years, pine-hardwood - over 50 years, pine plantation - 1 to 9 years, pine plantation - 20 to 40 years, pine plantation - over 40 years, cove-hardwood - 40 to 60 years, cove-hardwood - over 60 years, upland hardwood - 40 to 60 years, and upland hardwood - over 60 years. Within each of the 40 stands, five 0.1 ha (20 m x 50 m) study plots were randomly located and a 100% tally of all snags was made. A snag was defined as any dead or mostly dead standing tree at least 10.2 cm (4 in) dbh and 1.8 m (6 ft) tall. Total height and dbh were measured, and each snag was numbered at breast height with CFI paint and at stump height with an aluminum tag. Climable snags containing cavities were inspected to determine use by wildlife during warm months (May-September) and again during cool months (November-March). Sample size fluctuated due to snags falling between successive cavity inspection periods. For purposes of the determination of wildlife use, new cavity trees were continually added to the sample whenever found, so that some cavity trees were inspected as many as 3 times and some only once. Snag densities by forest type were compared by analysis of variance (Sokal and Rohlf 1973). The number of snags required for nesting by indigenous avian cavity nesters was estimated as discussed by Harlow and Gynn (1983) and compared with the number of snags found on the study area.

RESULTS AND DISCUSSION

Upland hardwood stands contained significantly ($P < 0.01$) greater numbers of snags than other stand types (Table 1). Forest management practices on the Clemson Forest have resulted in a large number of snags in all stand types compared to some other southern forests. McComb and Muller (1983) reported high snag densities in eastern Kentucky, but their study areas had received no management for 40 years or more. Snag densities on the Francis Marion National Forest (FMNF), in the Coastal Plain of South Carolina were found to be much lower than those in the present study (Harlow and Gynn 1983). Pine stands on FMNF contained approximately 84% fewer snags than hardwood and mixed pine-hardwood stands of the Clemson Forest, mostly because lightning struck and beetle (*Dendroctonus frontalis* and *Ips* spp.) killed trees are removed from the FMNF soon after detection. Snags are generally not removed from the Clemson Forest. Beetle kills are sometimes salvaged, but not as often as on the

Table 1.--Mean snag densities on the Clemson Experimental Forest ("North Forest") in the Piedmont of South Carolina, 1982.

Stand Type	Snags per hectare	
	$\bar{x}$	SE
Upland hardwood	50.3**	6.27
Cove hardwood	37.3	4.56
Pine hardwood	31.2	2.86
Pine plantation	21.3	2.96

** $P < 0.01$

FMNF. The hilly terrain on the Clemson Forest makes some areas inaccessible for salvage whereas a number of private salvage operators eagerly compete for dead and dying timber on the more accessible FMNF. Forests of the Coastal Plain also have a smaller hardwood component than those of the Piedmont, and the FMNF is open to public firewood cutting. Firewood cutting is strictly prohibited on the Clemson Forest, except in designated areas which were not part of the study area. Prescribed fire is used more frequently in pine stands of the FMNF than those of the Clemson Forest. Additionally, one of the major management practices in hardwood stands of the Clemson Forest has been to girdle or chemically inject undesirable stems.

Differences in biotic and abiotic factors in the Coastal Plain and the Piedmont may also explain differences in snag densities. There are probably a greater variety of diseases operating as tree mortality factors in the Piedmont. For example, littleleaf disease (*Phytophthora cinnamomi*) is frequent on the Clemson Forest due to the prevalence of red clay soils but is mostly absent from the sandy soils of the Coastal Plain. Climatic factors such as ice storms are more frequent and severe in the Piedmont than in the Coastal Plain.

Snag densities on the Clemson Forest were much greater in the 10.1-25.0 cm diameter class than in the larger diameter classes (Table 2). Sixteen snags were in such an advanced stage of decomposition that an accurate dbh measurement was impossible. These snags were included in the calculation of density by forest type but were excluded from density by diameter class and forest type. Estimates of optimum snag size and densities required to support selected cavity-nesting birds at various population levels are presented in Table 3. These requirements should be considered minimum because no reserve snags were included in the estimates. Bull and Meslow (1977) and Thomas et al. (1979) recommended 16 and Evans and Conner (1979) 10 reserve snags for each snag utilized; but at this time, there is no biological basis for reserve snag estimates (Harlow and Gynn 1983). Cavity-nesters that require snags in the 10.1-25.0 cm dbh range, such as the downy woodpecker (*Picoides pubescens*), Carolina chickadee (*Parus carolinensis*), and eastern

Table 2.--Mean snag densities by diameter class on the Clemson Experimental Forest ("North Forest") in the Piedmont of South Carolina, 1982.

Dbh Class (cm)	Snags per hectare				
	¹ UHW	² CHW	³ PHW	⁴ PP	Overall
10.1-25.0	41.8	28.8	23.8	14.7	27.3
25.1-40.0	6.3	4.8	6.3	5.8	5.8
40.1-55.0	0.8	1.5	0.8	0.2	0.8
> 55.0	0.5	0.3	0.0	0.0	0.2
Total	49.3	35.3	31.0	20.7	34.1

- ¹Upland hardwood
²Cove hardwood
³Pine hardwood
⁴Pine plantation

Table 3.--Optimum snag size and minimum snag densities for selected cavity-nesting birds in the Southeastern United States.

Species	¹ Dbh of cavity tree (cm)	² Snags/ha required to support various population levels		
		100%	60%	20%
Pileated woodpecker	45.7-66.0	0.15	0.10	0.02
Red-bellied woodpecker	35.6-53.5	0.52	0.32	0.10
Downy woodpecker	15.2-25.4	0.32	0.20	0.07
Barred owl	50.8+	0.10	0.05	0.02
Wood duck	50.8+	0.30	0.17	0.05
White-breasted nuthatch	30.5+	0.35	0.20	0.07
Tufted titmouse	30.5+	0.90	0.54	0.17
Eastern bluebird	20.3+	0.25	0.15	0.05
Carolina chickadee	15.2+	0.69	0.54	0.15
Total	-----	3.58	2.27	0.70

- ¹Adapted from Evans and Conner (1979)
²Adapted from Harlow and Gynn (1983)

bluebird (*Sialia sialis*) probably can find sufficient snags to support 100% maximum population levels on the Clemson Forest (Tables 2 and 3). Avian species that utilize snags in the 25.1-40.0 cm dbh range can also find favorable habitats in terms of the density of suitable-sized snags. This group includes species such as the tufted titmouse (*Parus bicolor*) and the white-breasted nuthatch (*Sitta carolinensis*). The Clemson Forest does not contain adequate numbers of suitable snags for species that require larger snags (dbh 40.1-55 cm and greater) such as the pileated woodpecker (*Dryocopus pileatus*), red-bellied woodpecker (*Melanerpes carolinus*), barred owl (*Strix varia*), and wood duck (*Aix sponsa*).

Snags containing cavities made up only 8.8% of all snags tallied in the original survey

(N = 654). Seasonal cavity inspections are still underway, but preliminary results (N = 107) indicate a high rate of utilization by southern flying squirrels (*Glaucomys volans*) (Table 4). Few inspections have taken place during the peak nesting season for most avian cavity-nesters, and it is expected that the rate of utilization by birds will increase as the study continues. Undoubtedly, some snags for which wildlife use could not be determined were being used by birds as roosting sites. On several occasions, cavities initially occupied by downy woodpeckers and even the large pileated woodpecker, were occupied by flying squirrels at the next inspection period. In a study on interspecific competition for red-cockaded woodpecker cavities on the FMNF, Harlow and Lennartz (In Press) found that flying squirrels used 32% of the cavities inspected. Whether there is direct aggressive conflict between flying squirrels and other species is not known. Silver-haired bats (*Lasiurus noctivagus*) were found roosting behind the loose bark of snags and are, therefore, not dependent on the presence of cavities. A number of herptofauna were observed during cavity inspections, but no attempt was made to enumerate or identify these species.

Table 4.--Utilization of snags as cavity sites by various wildlife species on the Clemson Experimental Forest ("North Area") in the Piedmont of South Carolina, 1982-83.

Species	Percent of cavity inspections				
	¹ CHW	² UHW	³ PHW	⁴ PP	Overall
Southern flying squirrel	23.8	35.7	36.4	43.6	36.4
Gray squirrel	14.3	7.1	9.1	2.6	7.2
Downy woodpecker	4.8	----	3.0	2.6	1.1
Pileated woodpecker	----	----	----	10.0	2.1
Red-bellied woodpecker	----	----	----	2.6	0.9
Red-headed woodpecker	----	----	----	2.6	0.9
Brown-headed nuthatch	----	----	----	2.6	0.9
Common flicker	----	7.1	----	----	0.9
Silver-haired bat	----	----	3.0	2.6	1.9
Undetermined	57.1	50.0	45.4	30.8	43.0

- ¹Cove hardwood
²Upland hardwood
³Pine hardwood
⁴Pine plantation

CONCLUSIONS

Management practices that favor the creation and retention of snags have resulted in high snag densities on the Clemson Forest compared to other managed southern forests. Snag densities are

probably adequate for cavity-nesting species that can utilize snags 40 cm dbh or less but may be limiting for species that require larger snags. A large percentage of snags with cavities are utilized by southern flying squirrels. Where flying squirrels are abundant, competition between other cavity-dependent wildlife species and squirrels may be serious.

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Use of Dead Trees by the Endangered Indiana Bat¹

John T. Brady²

Abstract.--Four Indiana bat nursery colonies have been found in riparian habitat. Three used recently dead trees with exfoliating bark and one used a hollow branch. Threats include deforestation and stream channelization. Management recommendations include maintaining riparian forest especially large, recently dead trees; restore riparian forest and implement research on Indiana bat summer habitat.

INTRODUCTION

The Indiana bat is a medium sized member of the genus and closely resembles the little brown bat (Myotis lucifugus). It is a monotypic species that occupies the eastern half of the United States. They hibernate in caves and mines from October to April with large hibernating populations occurring in Indiana, Missouri and Kentucky (Brady et al., In Press). Recent studies indicate that maternity colonies are formed mostly in riparian and floodplain habitat of small to medium-sized streams (Humphrey et al., 1977; Cope et al., 1978; Sparling et al., 1979; Gardner and Gardner, 1980). The maternity colonies that have been found have used dead trees (Humphrey et al., 1977; Cope et al., 1978).

CAUSES FOR ENDANGERED STATUS

The Indiana bat has been designated an endangered species by the U.S. Fish and Wildlife Service and is protected under the Endangered Species Act of 1973, as amended (U.S. Fish and Wildlife Service, 1978). A recovery plan has been prepared and should be available in late 1983 from the U.S. Fish and Wildlife Service.

The most important reasons for the decline of this species is human disturbance of hibernating bats causing the bats to arouse and use their stored fat supply. Vandalism and alteration of cave entrances, thus changing the cave microclimate, are also important. (Brady et al., In Press)

¹Paper presented at the Snag Habitat Management Symposium (Northern Arizona University, Flagstaff, Arizona, June 7-9, 1983).

²John T. Brady is Team Leader of the Indiana/Gray Bat Recovery Team and a wildlife biologist with the St. Louis District Corps of Engineers, St. Louis, Missouri.

SUMMER HABITAT

Three of the known nursery colonies occurred in riparian habitat in east central Indiana. The habitats of the two that occurred along the Big Blue River were described by Cope et al. (1978). Thirty-eight percent of the floodplain was forested including bottomland forest stands as well as strip woods adjacent to the river and pastured woodlots. The following species listed in order of importance made up 90 percent of the riparian trees: Acer negundo, A. saccharinum, Fraxinus sp., Plantanus occidentalis, dead tree, Celtis occidentalis, Ulmus americana, Salix sp., Populus deltoides, Juglans nigra, Gleditsia triacanthos, Aesculus glabra, and Ulmus rubra. Fifty-four percent was cropland with mostly corn and some soybeans, 7 percent was pasture and fallow fields, and 1 percent was ponds. The third maternity colony that was studied and described by Humphrey et al. (1977) was located in similar riparian habitat (Cope et al., 1978).

Cope et al., (1978) believed that the best foraging habitat is mature riparian forest at least 30 meters wide on both sides of the stream. Indiana bats would not fly over open spaces. The summer habitat was occupied from mid-May to mid-September (Humphrey et al., 1977)

The roost trees of three nursery colonies in east central Indiana have been described (Humphrey et al., 1977; Cope et al., 1978; Brack, Personal Communication). Another nursery colony was reported to have been in the hollow branch of a riparian tree in northwest Missouri (Humphrey et al., 1977).

The nursery colony reported on by Humphrey et al. (1977) first used a dead American elm (Ulmus americana) and moved to a dead bitternut hickory (Carya cordiformis) after the elm was destroyed by land clearing. The colony also used a nearby live shagbark hickory (C.ovata) as an alternate roost. The bats roosted under loose bark on the dead bitternut. Humphrey et al. (1977) believed that alternating between the dead bitternut and live shagbark gave the bats a thermal advantage under different

weather conditions. He believed that the dead trees were selected because they were more effective in trapping solar radiation since they did not have foliage to block sunlight and had little water to stabilize temperature.

Two other nursery colonies were discovered by Cope et al. (1978) and both occurred in dead cottonwood trees (*Populus deltoides*) (Cope, Personal Communication). Brack (Personal Communication) described one of these trees as follows:

"The roost tree had several large slabs of loose bark on the major limbs, while the remainder of the bark, both on the limbs and the tree bole, had fallen away. Only six or seven large branches remained on the tree; all the smaller branches were gone. The tree leaned over the river at an angle of about 15° from perpendicular. A typical component of riparian woody species was found on the floodplain near the roost...."

Another important characteristic of summer habitat was the size needed to support a colony. Individual nursery colonies have ranged from 50 bats occupying 0.8 kilometer of stream (Humphrey et al., 1977) to 100 bats occupying 1.2 kilometer (Cope et al., 1978). An average population density for suitable riparian habitat of 75 bats per kilometer has been suggested (Cope et al., 1978).

THREATS TO SUMMER HABITAT

Threats to summer habitat include deforestation and stream channelization for agricultural drainage and surface mining (Brady et al., In Press). In Illinois, Conlin (1976) reported that 30 percent of the stream were channelized and, if future plans were implemented, the total would rise to 45.5 percent. Some channelized streams support Indiana bat populations (Brack, 1979; Humphrey et al., 1977) after riparian vegetation has become established. LaVal and LaVal (1980) believed that summer habitat is not presently limiting Indiana bat populations, however, Bowles (1981) warns that clearing can lead to the fragmentation of wooded habitat along streams.

One direct threat to potential roost trees is the increased demand for wood as fuel. Firewood collections on national forests remove snags (Conner, 1978).

RECOMMENDATIONS

Riparian forest should be maintained throughout the range of the Indiana bat to the greatest extent practicable. In addition, a number of recommendations have been made in the Indiana Bat Recovery Plan (Brady et al., In Press):

1. Maintain large dead trees. Since a given roost site is believed to be suitable for only

2-8 years (Humphrey et al., 1977; Brack et al., 1982) a constant supply is needed.

2. Restore forest cover to channelized streams and ditches to a width of at least 30 meters on both sides. If possible a stream that is widened should be widened from one side only, leaving the opposite bank natural. Any clearing should be done between 15 September and 1 April to avoid nursery colonies.

3. Maintain water quality, since one of the main food items of Indiana bats is aquatic insects.

4. Locate and investigate more nursery colonies, since only three nursery colonies have been studied.

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The Importance of Snags to Pine Marten Habitat in the Northern Sierra Nevada¹

Sandra K. Martin and Reginald H. Barrett²

Abstract. Snags were found to represent 23% of all dens located during a study of pine marten (*Martes americana*) ecology conducted on the east slope of the Sierra Nevada. Use of snags as den sites by two geographically isolated groups of pine marten occupying dissimilar habitats within the study area was significantly different. Relative levels of snag utilization may be related to the availability of other preferred den types within a specific marten home range.

INTRODUCTION

Heavy trapping pressure and major loss of habitat through fires and logging have been blamed for the extreme reductions exhibited by many pine marten (*Martes americana*) populations in North America in the past century (Barbant 1922, Yeager 1950). Conservationists in California, alarmed by declines in local marten populations which began as early as 1900, urged the passing of a legislative ban on marten trapping in the state (Taylor 1913, Grinnell et al. 1937). Such a ban was enacted in 1953 and remains effective to date. By the 1970's, casual and intermittent information suggested that marten populations had regained a healthy status wherever semi-secluded tracts of appropriate forest habitat were found in the state, but few detailed studies of marten in California existed (Schempf and White 1977). In 1979, University of California personnel, in cooperation with the U.S. Forest Service, undertook long-term investigations of pine marten ecology. The data presented below are part of this larger study.

METHODS

The study was conducted in a 40 km² area defined by the upper watershed of Sagehen Creek, located on the east slope of the Sierra Nevada in the Truckee Ranger District, Tahoe National Forest, California. Elevations in the study area range from 1880 m in the east to 2620 m on the western edge, 5 km from the Sierra Nevada crest. Major habitat types in the watershed include those defined by meadow/fen/lodgepole pine (*Pinus contorta*) complexes in riparian zones at lower elevations. Drier forests dominated by Jeffrey pine (*Pinus jeffreyi*) are found on south-facing

slopes. The Jeffrey pine stands mix with white fir (*Abies concolor*) at higher elevations. Red fir (*Abies magnifica*) becomes prevalent on even higher mountain slopes.

Field work from which data below were extracted began in June 1981 and continues to date (June 1983). Pine marten were livetrapped in 20 x 20 x 60 cm Tomahawk traps baited with fish and commercially prepared scent. The traps were placed at stations on a 200 x 600 m grid. Trapped marten were drugged with ketamine and acepromazine for handling, and a radio collar was placed on each marten.

Radio collared marten were located once daily with radio receiving equipment and hand held antennas. Marten were tracked to their precise locations. Active marten could often be sighted at a distance while being followed, and the dens of inactive marten could be directly approached.

Habitat was characterized by collecting data regarding the vegetation on 0.1 acre (0.25 ha) circular plots. Plot centers were placed using the marten trapping grid described above. Data collected included tallies of all deadwood features on the plots. Deadwood was interpreted as comprising all snags, stumps, and logs. Specifically, a snag was tallied when found to be greater than 20 cm in diameter at breast height (DBH) and taller than 2 m. A stump was counted if it was at least 20 cm wide at its highest point. A stump was defined as being less than 2 m tall. A log was counted on the plot when it was at least 40 cm wide at a point 1.5 m above its base, at least 2 m long, and at least half of the log lay on the plot.

Data used below to estimate densities of deadwood features in different subregions of the study area were taken from habitat plots located within the home ranges of radio collared pine marten. Den sites were tabulated for eight individual marten (four ♂: four ♀). Only dens found at least 24 hours apart during tracking were counted. For instance, five locations of the

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² Authors' address; Dept. of Forestry and Resource Management, University of California, Berkeley, Ca. 94720

same marten in the same den in a single 24 hour (midnight to midnight) period would be tabulated as one den site location.

Relationships between marten sex and den type, and between geographic location of marten dens and den type, were examined with the 2 x 2 test of independence using the G-statistic (Sokal and Rohlf 1969: 591-92). A Student's t test, modified to account for $\sigma_1^2 = \sigma_2^2$, was used to compare average densities of habitat components in two different subregions of the study area (Cochran 1964).

RESULTS

Pine marten investigated in this study typically occupied a den for periods ranging from one to seven days. They remained inactive within the den for several hours at a time, often leaving to hunt and returning later. Marten are usually solitary except during brief mating liaisons in summer. Another social grouping forms when kits stay with their mother from birth in early spring until late summer. Members of these social groups often occupy the same den simultaneously.

A common movement pattern identified was for a pine marten to occupy a den for one or two days, then shift to another den within a few hundred meters of the first. Another shift would occur a day or two later. Dens within one specific area of the home range were often used for a few weeks, with the marten then completely shifting activity and den occupation to another area of its home range. Specific den sites were often used again after the initial occupation. Home ranges of the pine marten overlapped to varying degrees, and some sites were used by two or even three individuals at different times.

Types of den sites included the following categories; snags, stumps, logs, the canopy of trees, willow (*Salix* spp.) clumps, other brush, rock slides, and subnivean dens of unknown structure. Snags represented 23% of all den sites found (n=250). When only those dens used more than once were considered, snags were found to incorporate 27% of the total (n=90).

Dens were divided into the categories "snags" and "other dens". Den type was then found to be independent of the sex of the occupying marten ($G=0.301$, $\chi^2_{\alpha=0.05, d.f.=1}=3.841$). Marten den locations were also divided into two geographic categories; those of marten located in the western half of the study area, above 2250 m elevation (upper basin marten), and those found in the eastern end of the watershed (lower basin marten). The independence of snag and non-snag dens was tested with these two geographic categories. The null hypothesis of independence was rejected ($G=7.268$, $\chi^2_{\alpha=0.05, d.f.=1}=3.841$). Specifically, marten in the lower basin area used proportionally more snags as dens than did upper basin marten (table 1).

Snag densities for each of these two geographic areas were taken from habitat plots within

Table 1. Den types used by pine marten in the upper and lower subregions of Sagehen Creek Watershed.

	Upper Basin	Lower Basin
Total number of den sites located	165	85
Number of snag dens	29	28
Percent of total	17.6	32.9
Number of deadwood dens	121	49
Percent of total	73.3	57.6

the designated areas. Mean snag densities were 10.74/acre (26.54/ha) in the lower basin (below 2250 m elevation) and 8.78/acre (21.70/ha) in the upper basin (table 2). Using a modified t test, no significant difference between these two means was found (test statistic=0.699, $t'=1.674$).

Deadwood dens (snags, stumps, and logs) pooled together represented 68% of all marten den sites. As with snag dens alone, the hypothesis of independence between geographic location (upper and lower basin) and den type (deadwood and other dens) was rejected ($G=6.224$, $\chi^2_{\alpha=0.05, d.f.=1}=3.841$). Marten

in the upper basin were found to be using proportionally more deadwood dens than those in the lower basin (table 1).

Densities of stumps and logs in the two geographic areas were obtained in the same manner that snag densities were calculated. Modified t tests indicated that stump density in the upper basin was significantly higher than that in the lower basin (test statistic=2.32, $t'=1.680$)(table 2). A similar result was found when log densities in the upper and lower basin areas were compared (test statistic=3.0, $t'=1.671$)(table 2).

DISCUSSION

Snags are an important habitat component for pine marten in the Sagehen Creek watershed. One quarter of all den sites located for eight radio collared marten were in snags. The sex of marten appears irrelevant to discussions of den type selection. Geographic location, i.e. separating marten found in the upper or lower elevations of the study area, had a significant effect on analysis of den type selection. This geographic separation is justifiable on two counts; the categories represent two completely divided groups of marten occupying dissimilar habitat. Home ranges of the four marten found in the lower basin overlap extensively, but none of these overlap with home ranges of any upper basin marten. A similar situation exists among the four upper basin marten. Marten in the lower basin occupy lodgepole pine/white fir forests. Those in the upper basin are found in red fir/white fir forests.

Marten in the lower basin used snags proportionally more than did upper basin marten. However,

Table 2. Average densities of deadwood features in the upper and lower subregions of Sagehen Creek Watershed.

	Snags per acre			Snags per hectare	Stumps per acre			Stumps per hectare	Logs per acre			Logs per hectare
	n	$\bar{x}$	s^2		n	$\bar{x}$	s^2		n	$\bar{x}$	s^2	
Upper Basin	41	8.78	170.98	21.70	41	16.10	169.39	39.78	41	13.17	197.20	32.62
Lower Basin	27	10.74	99.43	26.54	27	8.89	148.72	21.97	27	4.44	94.87	10.87

snag densities appear to be similar in these two areas. Marten in the upper basin used more deadwood dens overall than did marten in the lower basin. These facts appear somewhat contradictory, but when stump and log densities in the two subregions are compared, a probable explanation emerges. The upper basin habitat provides a greater number of stumps and logs as possible den sites for marten than can be found in the lower basin. Marten are opportunistic, to a degree, in den selection. Deadwood sites provide preferred den locations, but where densities of snags, stumps, and logs are not high, other habitat features are utilized.

Snags probably gain importance as marten den sites in areas where logging has not recently occurred, or where stump and log densities are naturally low. A history of timber harvest activities in the Sagehen Creek basin reveals that extensive logging occurred at lower elevations between 1900-1920, and that a timber sale in 1967 resulted in strip-cut harvests in the upper basin (West 1982). The logging operation of 16 years ago is the most likely reason for the current high log and stump densities found in the upper basin.

Further analyses of den characteristics are being undertaken, and may disclose the importance of features beyond simple availability in marten den selection. Characteristics of suspected significance include size (DBH, height, and length), state of deterioration, proximity and amount of overhead canopy cover, and clustering of acceptable dens.

Snags should be respected as potential den sites in all areas where the marten occurs. However, snags are particularly important where logging has not been common. The natural decay of snags would

also be a primary factor in providing stumps and logs for marten dens in such undisturbed habitat.

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Seasonal Selection of Tree Cavities by Pygmy Nuthatches Based on Cavity Characteristics¹

Douglas B. Hay² and Marcel Güntert^{3,4}

Abstract.--Eighteen characteristics of 46 cavities used seasonally by Pygmy Nuthatches were compared to determine factors influencing cavity choice. Seasonally used cavities differed significantly in from 1-5 characteristics. Snag management should provide for seasonality in snag/cavity quality and bird choice.

INTRODUCTION

The importance of snags and dead wood within live trees to populations of secondary cavity nesting birds is well documented (eg. Allen and Nice 1952, Balda 1975, Cunningham et al. 1980). Further support for their value has been obtained where cavity density was increased by the supply of nest boxes (eg. von Haartman 1957). Several investigators have offered management proposals of a minimum number of snags necessary to maintain populations of secondary cavity nesters (SCNs) (eg. Balda 1975). Silviculture practices have begun to incorporate these recommendations.

A basic assumption in most present management plans is that a sufficient quantity of snags of a minimum size will provide cavity nesters (both primary and secondary) with suitable nest sites. Yet to the birds a snag may not be a snag; a cavity may not be a cavity. Variation in the macro- and/or microhabitat of the snag or cavity may affect the suitability of the site for a nest. Furthermore many SCNs are resident species and may select different cavities as nocturnal roost sites (Cunningham et al. 1980). These species, more correctly classified as secondary cavity users (SCUs) may take advantage of a cavity's qualities seasonally at which time the site is preferred.

The most common permanent resident SCU in coniferous forests of western North America is the Pygmy Nuthatch (*Sitta pygmaea*). The species is unique in that it roosts communally in tree cavities normally in groups of 10-14 birds (Güntert

unpub.). This pattern is observed throughout the year, with the exception of the nesting period. Pygmy Nuthatches are further known to select different cavities for nesting and winter roost sites (Cunningham et al. 1980). Güntert (unpub.) has identified summer and fall/spring roosts as well.

The objectives of this study were: 1) to determine characteristics which distinguish those cavities preferred within a season by Pygmy Nuthatches, 2) to identify the possible benefits of those cavity characteristics selected within a season, and 3) to outline important considerations for the future management of habitat for Pygmy Nuthatches and other SCUs.

STUDY AREA

The study area was located within 3.4 km of the canyon rim at Walnut Canyon National Monument, Coconino County, Arizona. Ponderosa pine was the predominate vegetation type in the area. Mature pine stands with high snag densities characterize the community within the monument. North of the monument boundary in Coconino National Forest land logging and fuel wood collecting have removed virtually all snags and have greatly reduced foliage volume. Forest Service road 303 separates the two jurisdictions.

METHODS AND MATERIALS

Characteristics of 46 cavities used seasonally by banded flocks of Pygmy Nuthatches were recorded. Cavities were assigned to general seasonal categories (eg. nests, summer roosts, winter roosts, and fall/spring roosts) according to observed use by the birds.

Fourteen characteristics were used to discriminate between seasonal cavity usage groups. The total tree height, DBH, and general condition were recorded for the tree containing the cavity. The height to the cavity and diameter of the trunk or branch surrounding the cavity were recorded.

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²Douglas B. Hay is Instructor of Biological Sciences, Northern Arizona University, Flagstaff.

³Marcel Güntert is Research Associate, Northern Arizona University, Flagstaff.

⁴Present address is Museum of Zoology, University of Zurich, Switzerland.

Measurements were taken of cavity depth, width, vertical length, entrance hole area, and accessory holes. The hole's direction of orientation and placement were noted. Cavity placement (branch, trunk) and angle (of the branch) were also noted.

Cavity volume was directly measured in over 90% of the cavities. A vacuum hand pump was used to fill an elastic reservoir (condom) located within the cavity. When the cavity space was filled the pump was removed and the water within was measured in a 500cc graduated cylinder. Cavity volumes which could not be measured in this way were estimated from inside dimensions.

Daily radiation absorbed by the cavities was calculated for four representative days of the year. A series of four clinometers were constructed, enabling the observer to trace the arc of the sun on February 15, April 15, June 15, and August 15, regardless of the date of data collection. The time and degree of cover which would obstruct direct insolation were noted by the observer for each date. Data was called out to an individual recording the information on the ground. Qualitative cover categories of clear sky, light shade, medium shade, and heavy shade were used. Tabulated values of direct radiation were corrected for shade periods by reducing the values by 20, 40, and 60% for light, medium, and heavy shade, respectively. These percent reductions were determined from the measurement of qualitative shade classes on the penetration of radiation recorded by a light meter. Indirect solar radiation was calculated as a time and date specific percentage of the direct solar radiation penetrating the atmosphere on a clear day (Gates 1980). Calculations of daily absorbed radiation were made using Morhardt's (1975) equation:

$$Q = (A \cdot SA)DR + 0.5((A \cdot IR) + A \cdot R(DR + DI))$$
 where A = absorbtivity, SA = radiated surface area or ((cavity length/cavity diameter)/cosine of the angle of the sun), DR = direct radiation, IR = indirect radiation. Calculations were made using a specifically designed computer program, which corrected for shade.

Differences between characteristics of seasonal cavities were evaluated by two methods. Mean values of recorded characteristics of nests, summer roosts,

fall/spring roosts, and winter roosts were tested for significance using two-sample t-tests. A discriminant analysis was employed to determine those characteristics most important in distinguishing between seasonal usage groups. In this test fall and spring roosts were split into fall roosts and those cavities used in both the fall and the spring. Nests used through the summer and fall were also assigned to a specific group. Each cavity was assigned to only one of the usage groups.

RESULTS

Statistical comparisons between mean characteristics of seasonal cavity groups indicated nest cavities were most distinctive (Table 1). Nest cavities are significantly lower in the tree than summer roosts (SR), fall and spring roosts (F/S), and winter roosts ($t=2.29$, $.010 < p < .025$; $t=3.88$, $p < .005$; $t=3.25$, $p < .005$; respectively). SR, F/S, and winter roosts were located in significantly taller trees ($t=2.57$, $.010 < p < .025$; $t=5.34$, $p < .005$; $t=3.62$, $p < .005$; respectively). Nests averaged smaller entrance holes than SR and F/S roosts ($t=1.75$, $.025 < p < .05$).

Fewer characteristics distinguished between winter, SR, and F/S roosts. Winter roosts differed in having significantly smaller entrance holes than SR and F/S cavities ($t=44.8$, $p < .001$; $t=42.8$, $p < .001$; respectively). F/S roosts were located higher in the tree than SR roosts ($t=2.08$, $.025 < p < .05$).

Cavities were usually located in the trunk of snags or lightning strikes or dead branches of live trees. The majority of nests and winter roosts were located in trunks (Table 2). SR and F/S roosts were distributed somewhat evenly between trunks and branches.

Calculations of average daily absorbed radiation indicated a wide degree of variation within a seasonal usage group (Table 3). Comparisons of mean absorbed radiation were only significantly different between SR and F/S roosts ($t=2.95$, $.005 < p < .010$). This difference occurred in the Spring (April 15) during which time F/S roosts absorbed more radiation

Table 1.--Mean values of characteristics of seasonally used cavities.

		Tree		Cavity				Hole			
		height	DBH	height	diameter	depth	width	length	volume	accessory hole area	area azimuth
		(m)	(cm)	(m)	(cm)	(mm)	(mm)	(mm)	(cc)	(cm ²)	(cm ²)
Nests	$\bar{X}$	9.8	39.2	5.6	25.2	63.8	73.1	147.1	528.9	5.0	13.0 109.5
(n=10)	SD	5.8	20.0	2.1	18.3	22.5	29.5	76.8	150.5	1.2	0.9 91.1
SR	$\bar{X}$	18.9	64.5	7.9	22.0	73.5	73.4	148.2	630.2	36.0	22.2 160.5
(n=11)	SD	9.9	19.5	2.5	11.5	19.7	30.9	70.2	374.6	85.6	15.1 112.1
F/SP	$\bar{X}$	24.5	63.3	10.8	34.9	75.6	68.1	172.6	616.2	1.5	21.7 161.8
(n=9)	SD	6.1	17.3	3.5	26.1	24.0	13.4	24.9	226.8	0.4	14.0 130.7
Winter	$\bar{X}$	23.2	73.1	9.3	56.6	73.2	68.7	137.2	683.1	3.6	11.2 188.2
(n=8)	SD	9.1	20.3	2.6	22.6	21.6	18.9	44.5	393.5	0.5	6.0 58.6

Table 2.--Location of seasonal cavities (%).

	Trunk	Branch
Nests (n=10)	91.7	8.3
SR (n=11)	45.5	54.5
F/SP (n=9)	66.6	33.3
Winter (n=8)	87.5	12.5

Table 3.--Mean daily absorbed radiation of seasonally used cavities(Langleys/day).

		Breeding (Jun 15)	Summer (Aug 15)	Spring (Apr 15)	Winter (Feb 15)
Nest	$\bar{X}$	2625	5470	5939	601
	SD	1695	2402	2527	316
SR	$\bar{X}$	3392	6197	6176	925
	SD	694	1980	2909	339
F/SP	$\bar{X}$	7061	10957	14265	1504
	SD	7179	8983	9134	1229
Winter	$\bar{X}$	4727	7057	6937	989
	SD	4680	7114	5654	957

A discriminant analysis was made to differentiate between six seasonal usage groups. These groups were nests, summer roosts, fall roosts, nests used during the summer and fall of the same year, winter roosts (usually used during other seasons), and fall and spring roosts. Eight variables were found to be significant in explaining the variation between groups: tree height (TH), DBH, height of cavity in the tree (CH), diameter of the trunk or branch surrounding the cavity (DC), cavity length (CL), accessory hole area (AHA), compass orientation of the hole (HAZ), and density of the wood (D).

On the basis of these eight characteristics nests were found to be significant from all groups except nests also used in the summer and fall (Table 4). Summer roosts were significantly different from all other groups, except for those cavities used only in the fall. All other seasonal usage groups were insignificantly different from one another.

Three discriminant functions were used in the analysis. CH, AHA, DBH, and TH were included in the first function. The second discriminant function was based on DC. CH, HAZ, and D identified the third function. Together these functions correctly classified 65% of the 46 cavities.

Table 4.--Significance between groups as defined by discriminant analysis (n=46).

		Nests	SR	Fall	N,SR,F	Winter
SR	F	3.99				
	P	.00				
Fall	F	2.52	1.70			
	P	.02	.13			
N,SR,F	F	1.68	2.73	1.23		
	P	.13	.01	.30		
Winter	F	3.10	2.21	1.15	2.00	
	P	.01	.05	.35	.05	
F/SP	F	2.15	2.16	1.31	1.09	0.91
	P	.05	.05	.27	.39	.51

DISCUSSION

Several characteristics of the macrohabitat distinguished between cavities used seasonally. Trees housing nest cavities were shorter and consequently had a significantly smaller DBH. The selection of these smaller trees and lower cavities within them probably represents a response to wind. By utilizing cavities closer to the ground convective heat loss may be greatly reduced. Greater cavity height of Fall/SP roosts in comparison to SR was identified in more absorbed spring/fall radiation by the prior. In contrast nest cavities appear to be positioned to obtain moderate insolation, while being shielded from wind. Average radiation absorbed by nests was not significantly different from that calculated for any other cavity group during the breeding season.

A variety of microhabitat variables were useful in differentiating seasonal cavities. Entrance hole area and the area of other accessory holes both are important factors affecting the physical movement of air through the cavity (Hay unpub.). Larger hole areas and smaller cavity lengths increase the relative air flux. In addition the greater the relative difference in outside ambient temperature vs. inside (roost) temperature the more rapid the air movement. Selection of cavities with large entrance areas during periods of time when temperature differences are small and the birds are communal (Summer and Fall/Spring) encourages greater air flux. During much of the nesting period fewer birds are roosting together. Generally one to six nights after fledging the family switches to a SR (Guntert, unpub.). Winter temperature differences are high offsetting the negative effect of a smaller hole size on the mass transfer of air.

The location of more SR and Fall/SP roosts in branches may further aid communal birds to acquire adequate ventilation. Slanting branches allow individuals to position themselves closer to the cavity entrance, without the extra energy required to cling to the walls of vertical cavities.

Other characteristics distinguishing the microclimate were identified as significant in the discriminant analysis. The diameter of the trunk or branch at the cavity as well as cavity density and compass orientation at the entrance (azimuth) appear related to seasonal needs for convective and radiant heat gains or losses by the cavity. Bigger cavities with holes oriented more to the south may heat up more in the winter and be on the lee side of trees when northerly winds blow. Nest cavities facing east will warm faster in the mornings and be more protected by prevailing westerly winds. Less dense wood in nests and winter roosts buffers the cavities from rapid temperature shifts.

On the basis of these and other significant factors the discriminant analysis was unable to classify 35% of the 46 cavities correctly. However of those incorrectly classified 95% are located in the section of the study area which has been logged and heavily cut for fuel wood. This strongly suggests that alteration of the birds' habitat, resulting in considerable reduction in snag densities, forces Pygmy Nuthatches to use atypical cavities. Cavity selection appears strongly tied to a variety of seasonal behavioral and physiological responses of the birds (Hay, unpub.). The management practices of snags which do not provide an adequate range in snag and/or cavity quality may affect the overall biology of the species, its survivorship, and reproduction.

CONCLUSIONS

Seasonal cavities selected as nest and/or roost sites by Pygmy Nuthatches were found to differ in several characteristics. These factors contribute to interseasonal variation in the macro- and/or microhabitat of the cavity. In the absence

of an array of cavities from which to choose, the birds are forced to use atypical cavities within a season. As cavity selection is interrelated to the overall biology of the species, management of snag and/or cavity quality, rather than quantity, appears critical. We recommend more baseline research of this type conducted with the goal of determining important cavity characteristics for seasonal usage by resident secondary cavity users.

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Winter Communal Roosting in the Pygmy Nuthatch¹

William J. Sydeman and Marcel Güntert²

Abstract.--We have studied the communal roosting behavior of Pygmy Nuthatches in one extremely important cavity in a snag. Between 27 and 167 birds used the roost during the winter of 1983. Some nuthatches moved almost 2 kilometers nightly to reach this cavity. The number of birds and time of roosting were effected by weather conditions.

INTRODUCTION

Cavities in snags provide essential habitats for birds during many phases of their life histories. For migratory species, cavities provide the proper thermodynamic and protective environments for rearing young. Resident species may use cavities for predator avoidance and energy requirement during the non-breeding season as well. In particular, the survivorship of many over-wintering species may depend solely on their use of snags. The importance of snags may be underestimated with regards to the survivorship of many forest dwelling birds.

The Pygmy Nuthatch (*Sitta pygmaea*) relies on cavities during the winter for survival. Pygmy Nuthatches are one of the smallest (10-11 grams), resident birds of the Ponderosa Pine (*Pinus ponderosa*) forest near Flagstaff, Arizona. They are highly social, and live in groups of 5-20 individuals throughout the non-breeding season. In winter, nuthatches forage in flocks of 4-20 or more that jointly defend a group territory from conspecifics. In the late afternoon, birds gather and travel to a snag within their territory to spend the night. These communal roosts vary in volume and number of birds using them. The snag, where a communal roost is located, is the central focus of wintering birds (Norris, 1958). The largest reported roost of Pygmy Nuthatches is that of Knorr (1957), who estimated 150 birds using a snag in a montane area of Colorado.

Here we report on the communal roosting behavior of a large population of Pygmy Nuthatches in one particularly important snag during the winter of 1983. We will examine the biotic and abiotic

factors that play a role in promoting large roosting aggregations. Additionally, we will describe the distances traveled by nuthatches to reach this cavity, and the composition of this roosting association in terms of foraging flock membership.

METHODS

We have been studying Pygmy Nuthatch social organization and breeding biology at Walnut Canyon National Monument and in adjacent Coconino County Forest Service land since October, 1980. The study area is approximately 300 ha., 24.0 km. east of Flagstaff, and is dominated by mature stands of Ponderosa Pine with occasional patches of Pinyon Pine (*Pinus edibilis*), Juniper (*Juniperus* spp.) and Gambel's Oak (*Quercus gambelii*). Many snags are available to the birds in the National Monument, whereas few are present in the Forest Service land due to firewood cutting practices.

A large percentage of birds within this area have been color-banded to follow individual life histories. Nuthatches were banded with a unique color-combination. Group foraging territories have been mapped as a result of afternoon observations on the number of birds and identity of individuals in each group.

At approximately 1500-1600 hours, observations began at Walnut Canyon 50 (hereafter WC50), the communal roosting snag used extensively in 1983. The arrival of nuthatches was recorded for as many nights as possible from 14 January to 9 April, 1983. Generally, two well-trained observers participated in gathering data on the number of birds, and on the identity of individuals. Nuthatches were viewed entering the cavity using either a Bushnell Spacemaster or a Bausch and Lomb Explorer spotting scope(s).

We restricted our analyses to evenings when only a full complement of the data were obtained. For example, only those evenings when a full count was made on the number of birds roosting were used for statistical analysis. Similarly, only those nights when we were certain to have arrived before

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²William J. Sydeman is a graduate student in the Department of Biological Sciences, Northern Arizona University, Flagstaff, AZ, and Dr. Marcel Güntert was a post-doctorate student at NAU. Presently, Dr. Güntert is Professor of Anatomy, Universität Irchel, Zurich, Switzerland.

any birds had entered the roost were used in the analysis of time of roosting.

All regression models were developed using SPSS forward or stepwise procedures.

RESULTS

Number of Birds and Time of Roosting

A total of 33 accurate evening counts were made on the number of birds roosting in WC50. The count varied considerably with a high of 167 on 19 February and a low of 27 on 10 March (fig. 1).

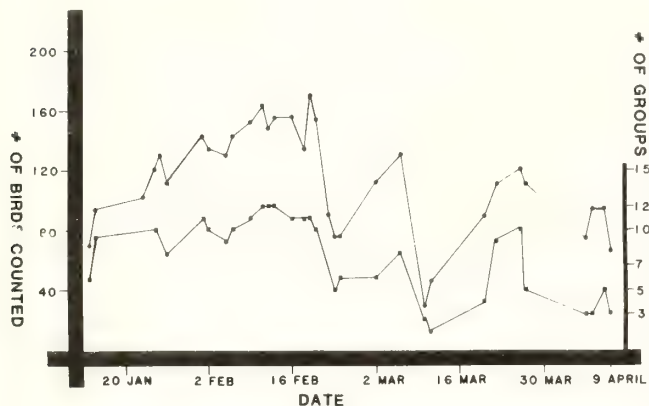


FIGURE 1. NUMBER OF BIRDS AND GROUPS COUNTED NIGHTLY

Figure 1.--Number of birds (left y-axis) and number of banded group (right y-axis) observed each night coming to WC50.

A steady increase in the number of roosting birds and the number of banded groups coming to roost is apparent from the beginning of the study through the first three weeks of February. Subsequently, the number of roosting birds dropped and peaked until the middle of April. These data suggest that roosting is a group phenomenon, and that the decision of where to roost is carried out as a group function, and not by individual birds. In addition, the consistent use throughout early February followed by a sudden decrease in numbers within a matter of days suggests that nuthatches are behaviorally tracking changes in environmental conditions. A threshold temperature or weather condition may trigger use of this snag as a roost.

Multiple regression analysis reveals that weather conditions do indeed affect the number of roosting birds. The presence of snow is the best predictor of cavity use and accounts for 26% of the variability in roosting numbers (Table 1). Temperature, barometric pressure and day in the winter cycle contribute an additional 10% in explaining the number of roosting individuals. Other predictor variables that were entered and found to be insignificant are minimum nighttime temperature, relative humidity, wind speed, cloud cover, and changes in barometric pressure. The full model explains only 36% of the variation in roosting

numbers. This is insufficient in describing the observed roosting association. Either additional data are needed on the effect of weather parameters on nuthatch roosting behavior, or biological factors possibly social constraints, play a role in maintaining large numbers of roosting birds.

Table 1.--Analysis of Variance Table for the Regression of the No. of Birds Counted Nightly with Weather Conditions (n=33).

Source	df	R ²	F	Signif.
Presence of Snow	1	.26	10.66	p < .005
Maximum Daily Temp.	1	.29	6.05	p < .01
BP @ 1700	1	.33	4.77	p < .01
Day	1	.36	3.89	p < .025
Residual	28			

Data presented with the addition of each variable listed.

Weather conditions not only affected the number of birds using this snag, they were important determinants of the initiation of roosting. Temperature at 1700 hours and the presence of snow account for 54% of the variation in roosting times (Table 2). Temperature is positively correlated ($r = .71$, $p < .0005$) with the time of roosting. On days when the temperature at 1700 hours was higher, the birds roosted later. Snow was negatively correlated ($r = -.61$, $p < .0005$). When snow covered the ground, birds roosted at an earlier time. A confounding effect is seen with day in the winter cycle which contributes an additional 16% to the model. As would be expected, daylight hours lengthened following the winter solstice, and the birds entered the roost at later times. The full model in this case predicts accurately when birds go to roost. From these data, it does appear that temperature and snow change Pygmy Nuthatch roosting behavior.

Table 2.--Analysis of Variance Table for the Regression of the Time of Roosting with Weather Conditions (n=33).

Source	df	R ²	F	Signif.
Temp. @ 1700 hrs.	1	.50	31.319	p < .0005
Day	1	.66	29.159	p < .0005
Presence of Snow	1	.70	22.985	p < .0005
Residual	29			

Data presented with the addition of each variable listed. Regression Equation: $Y = 1405.43 + 5.35 (\text{Temp. @ 1700}) + 1.01 (\text{Day}) - 37.28 (\text{SnowP})$.

Roosting Composition

The roost contained not only banded, but also many unbanded individuals. The number of banded and unbanded birds in each group, and the distance traveled by each flock to the communal roosting snag are summarized in Table 3. Most of the groups

Table 3.--Characteristics of Foraging Flocks of Pygmy Nuthatches.

Group	No. Banded	No. Unbanded	Total No.	Distance to WC50 (km.)
LB-east	9	3	12	0.664
Or	5	3	8	0.715
LB-west	6	9	15	0.859
DB-8	2	0	2	0.952
Y-east	2	2	4	0.974
Y-west	6	2	8	1.046
LG-west	5	5	10	1.176
DB-east	6	3	9	1.248
LG-east	11	2	13	1.256
Mauve	9	5	14	1.429
Red	8	12	20	1.509
White	9	3	12	1.682
Park-west	1	13	14	0.332

have at least 50% of their birds banded. All banded groups were located east of WC50. The distance traveled to the roost varied from .3 km. to 1.7 km. A total of 141 birds were monitored by taking observations on these banded foraging flocks. At least 79 of these birds were banded and 62 were unbanded. On 19 February, when the highest count of 167 birds was obtained, 96 unbanded birds were observed. Thus, in addition to our banded flocks, other groups of nuthatches from outside the study area were using WC50. The number of these groups is unknown, but the distance traveled to this snag was probably similar to those groups located to the east.

All of the banded flocks have been observed roosting at WC50. Banded birds whose complete color-band combination was determined comprised approximately 50% of all banded birds observed. Figure 2 shows the percent contribution of each banded group. It is clear that certain groups

contributed more to the roost than others. Generally, these were groups closest to the roosting snag. Light Blue-east and west and Orange compose the core groups of the WC50 roosting association. White and Red, whose territories are 1.7 and 1.5 km., respectively, from the roost, exhibited similar contributions to the cavity as did these closer groups. The Light Green and Dark Blue groups contribute least, although their presence at the roost is consistent. Yellow-east and west and Mauve contribute significantly to the roost and their distances range from .9 km. to almost 1.5 km.

Cavity Characteristics

WC50 is located in a dying Ponderosa Pine 78 feet above ground. The cavity has two entrances at equal heights, and located on the underside of broken-off branches where they intersect the trunk. One entrance faces to the northeast, while the other has a southwest exposure.

Exact cavity characteristics have not been taken owing to the height of the entrances. However, we can estimate the total volume and surface area needed to accommodate the maximum number of birds counted by extrapolating data collected on another previously measured winter roosting cavity. One particular cavity measured 1500 cc. and held, when packed, a maximum of 42 birds (D. Hay, pers. comm.). These nuthatches, in order to fit into this cavity, must have been stacking on top of one another. Stacking has been observed in aviary birds by groups of 4-12 individuals (D. Hay, pers. comm.). If the birds using WC50 stack, then a minimum of four times 1500 cc. must be available to fit the 167 birds observed roosting on 19 February, 1983. Therefore, the cavity must be at least six liters.

A more realistic assumption may be that the birds are not stacking, but are clinging to the walls of the cavity. An estimate of minimum surface area would then be appropriate in determining cavity size. The area needed to accommodate the ventral surface of a Pygmy Nuthatch is approximately 30 cm². Taking our high count of 167 birds, this means that a minimum surface area of 5,010 cm² is necessary. A measurement of this magnitude is equivalent to a bit more than .5 m².

DISCUSSION

The use of WC50 has increased dramatically this year over previous winters. Traditionally, only Light Blue-east and west, Yellow-east and west and Orange have used WC50 as a winter roost. Why have these additional flocks joined the roosting association at WC50 this year? This is especially puzzling considering that many winter cavities used by these new groups in previous years are still intact. We have already shown how weather changes affect the number of roosting birds. These data, unfortunately, are insufficient in explaining the total variation in roosting numbers. Since these data are preliminary, we cannot explain fully the increased use of this cavity.

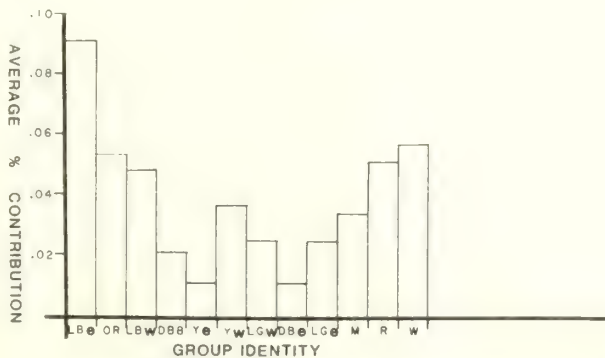


FIGURE 2. PERCENT CONTRIBUTION OF Banded GROUPS

Figure 2.--Percent contribution of each banded flock to the roosting association. Contribution is computed using only banded birds. Groups are listed in order from the closest to the furthest from the roosting snag.

There are, however, a number of theoretical hypotheses in reference to birds roosting in trees or in open areas that may provide some insight into communal roosting by the Pygmy Nuthatch. Lack (1968) proposed that communal roosts function to protect individuals from predators; certain birds roosting in the center of the group may be buffered by peripheral birds when a predator attacks. Ward and Zahavi (1973) have been proponents of the information-center hypothesis which is based on a differential in foraging success between individual birds. Communal roosts then function in the sharing of food localities or foraging techniques between less successful and successful foragers. Weatherhead (1983) has synthesized these two hypotheses and suggests that successful foragers are simultaneously dominant individuals in the roosting aggregation, and as such may secure the most predator proof position within the roost. As of yet, we have not tested any of the above hypotheses.

Lastly, there are a number of important management implications concerning communal roosting in the Pygmy Nuthatch. First, if a large communal roost can be identified, the birds using it may be monitored to assess population density. As the birds utilizing WC50 traveled a minimum of .3 km. to almost 2 km. to reach this snag, a large area may be effectively censused with little expenditure in time or manpower. The distance traveled to WC50 also points out the importance of a single snag to a large population of birds. Identification of these primary roosting cavities may be difficult, thus many snags within a particular area are needed to provide suitable roosts. The exceptional use of one cavity also points out the need for more detailed work on the microhabitats of cavities. Each cavity does not provide the same essential habitat requirements, especially

as these requirements change over time and are different for each species. Finally, one might argue that only one cavity is needed to provide a large number of birds with a suitable roost. However, the system we have studied is highly plastic, with fluctuations in cavity usage between years and within seasons. In previous years, other winter roosting cavities were used with equal frequencies of WC50 this year. The availability of numerous snags with cavities having the proper characteristics is critical to nuthatches and other species that rely on snags for over-wintering habitat.

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Decay Characteristics of Pileated Woodpecker Nest Trees¹

Roger D. Harris²

I analyzed decay and mortality characteristics of 42 pileated woodpecker (*Dryocopus pileatus*) nest trees in California. In addition to examining standing trees and wood chips from excavations, eight felled trees were sectioned to determine internal decay characteristics. All cavities in Pinaceae and hardwood trees were associated with decay. Chips excavated by pileated woodpeckers from undecayed softer wood were comparable in hardness to chips from harder wood that had decayed. Pileateds selected a nest cavity site on the basis of the structural quality of the wood and not just the fact that the tree was dead. Management recommendations stress the need for reserving hard snags and allowing for recruitment. Creation of snags by artificial means is not recommended.

INTRODUCTION

To make management decisions consistent with the retention of nesting habitat for pileated woodpeckers (*Dryocopus pileatus*), it is necessary to know their requisites for mortality and decay of nest trees. Conflicting results have been reported over whether pileated woodpeckers require decayed wood in which to excavate nest cavities. Conner et al. (1976) cultured wood samples from six pileated woodpecker nests (five in hardwoods and one in a conifer) and found evidence of decay fungus in each. However, Miller et al. (1979) examined wood chips from nine nests excavated by pileated woodpeckers in Pinaceae trees and found only four with signs of decay. They also sectioned and examined for decay two of the nest snags. Both cavities were excavated in sound wood, although limited areas of sapwood decay were present elsewhere in the trees. McClelland (1977) found chips from 50% of 22 nest excavations by pileated woodpeckers in Pinaceae trees with obvious evidence of heartwood decay.

Furthermore, Conner (1973:36) suggested that pileated woodpeckers apparently lacked the ability to make nest cavities in completely live trees. Yet, Conner et al. (1975) reported that the pileated often excavated through living hardwood cambium to reach a decayed heartwood core. Munro (In Bent 1939:192) observed pileated woodpeckers in British Columbia "cutting" into green cottonwood and popular, presumably *Populus trichocarpus* and *P. tremuloides*. Carriger and Wells (1919) likewise reported "several" pileated woodpecker nests in live aspens in California, where "plenty" of dead

trees were available. Sumner and Dixon (1953) also reported pileated woodpecker nest cavities in live wood in the Sierra Nevada.

This study attempts to resolve some of these conflicting results. Through an analysis of field data on pileated woodpeckers in California, I show that neither mortality nor decay necessarily has to be present as long as the wood is soft enough to be excavated. However, in all but tree species with the softest woods, pileated woodpeckers excavate nest cavities in dead portions that have been softened by decay.

METHODS

A search for active pileated woodpecker nest sites was made throughout California as part of a larger study on the nesting ecology of the species (Harris 1982). I found eighteen nests in 1979 to 1983. Also, over 350 letters were sent in spring 1980 to birders, land managers, forest owners, and biologists soliciting reports of recent nests. I accepted reports of 24 nest sites in which it was determined that eggs or nestlings had been present; pileated woodpeckers make false starts on nest holes and abandon nest cavities before laying (Bull 1975, McClelland 1977).

I examined all trees for decay characteristics. Hardness of tree was estimated by making a "standardized" thrust of a knife into the tree at breast height and also just below the nest hole, where bark (if present) had been removed, and noting penetration (for a 5-cm blade, very hard = < 1 cm, hard = $\geq$ 1 cm and < 2.5 cm, soft = $\geq$ 2.5 cm and < 5 cm, rotted = 5 cm). The test required equipment readily available in the field, and results were replicable. Top condition, limb condition, and percent of bark were estimated visually.

Causes of tree mortality could not be determined reliably because, for example, fungus may have infected snags after death, masking the

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²Roger D. Harris was a graduate student, Department of Forestry and Resource Management, University of California, Berkeley. Presently he is Director, Flat Rock Brook Center for Environmental Study, Englewood, N.J.

original agent(s) of mortality. In addition, tree mortality is usually a result of a combination of abiotic and biotic stress factors (Bega 1978).

I collected wood chips excavated by woodpeckers from 22 current nest cavities. Experienced wood technologists examined breakage patterns of wood chips to determine soundness. Presence of decay was noted based on fungal remains, rot, and discoloration. If wood chips were judged to be both sound and without macroscopic evidence of decay, they were further examined microscopically for fungal tubes, fungal remains, and rot.

No attempt was made to culture wood chips to identify fungal species. It cannot be reliably determined whether the cultured fungal species was initially present at the time the chips were excavated or had subsequently infected the wood while it was on the ground.

I also examined nest trees for internal decay characteristics and evidence of insect activity. Four nest trees were felled in late August 1980, well after the nestlings had abandoned their nests of the previous spring. Trees were cut horizontally into 2-m sections, nest cavities were sectioned vertically, and horizontal cuts were made immediately above and below the nest cavities. An additional four nest trees fell naturally in winter storms, and were also examined in the same manner as above for internal decay characteristics.

Time since death of Pinaceae nest snags was estimated by the criteria of Cline et al. (1980). Three age classes were delineated: young snags (estimated to be recently killed) had either intact or broken tops, twigs or needles present, >90% bark, and very hard wood; moderate-aged snags (estimated to be 4 to 8 years old) had twigs or branches present, very hard or hard wood, and >50% bark remaining; old snags (estimated to be older than 8 years) had broken tops, no twigs present, very hard or hard wood, and <50% bark remaining.

RESULTS

Pileated woodpeckers demonstrated plasticity in their choice of nest tree species, representing a range of green wood specific gravities which are indicative of wood hardnesses (Table 1). By the knife test, none of the trees were soft or rotten.

All Pinaceae nest snags had broken tops, except for four white firs with intact tops. (See table 1 for scientific names of trees.) Half of the coast redwoods, neither of the giant sequoias, and 60% of the hardwood nest trees had broken tops.

Tree Mortality

In seven of the eight live trees, nests were excavated in dead portions of the bole. In the eighth tree, an entirely living coast redwood, the cavity appeared to have been excavated through green cambium into sound heartwood. The nest hole was in an area of clear wood, not the site of a broken limb.

Table 1.--Tree species used for nesting by pileated woodpeckers.

Tree Species ¹	N	sp gr ²	% Snags	% Broken Tops
CR ³	2	0.300	50	50
BC ³	1	0.315	100	100
QA ³	2	0.344	0	0
GS ⁴	2	0.350	0	0
WF	13	0.365	100	69
WA	1	0.368	100	100
PP	9	0.370	100	100
RF	2	0.372	100	100
AE	1	0.421	100	100
D-F	4	0.444	100	100
BLM	1	0.520	0	0
CBO	2	0.529	0	50
MAD	2	0.537	100	100

¹CR = Coast Redwood (*Sequoia sempervirens*), BC = Black Cottonwood (*Populus trichocarpus*), QA = Quaking Aspen (*Populus tremuloides*), GS = Giant Sequoia (*Sequoia gigantea*), WF = White Fir (*Abies concolor*), WA = White Alder (*Alnus rhombifolia*), PP = Ponderosa Pine (*Pinus ponderosa*), RF = Red Fir (*Abies magnifica*), AE = American Elm (*Ulmus americana*), D-F = Douglas-fir (*Pseudotsuga menziesii*), BLM = Big Leaf Maple (*Acer macrophyllum*), CBO = California Black Oak (*Quercus kelloggii*), MAD = Madrone (*Arbutus menziesii*).

²Hardness of wood is based on specific gravity (sp gr) of green wood (Cockrell et al. 1971, Markwardt and Wilson 1935).

³Tree species in which pileated woodpeckers have been known to excavate nest cavities through green cambium.

⁴Tree species in which pileated woodpeckers excavated a nest cavity in undecayed wood.

All pileated woodpecker nest trees in Pinaceae were snags. By snag age class, 32% were young, 46% moderate-aged, and 21% old. Fifty-six percent of the ponderosa pines, but none of the white firs were old.

Decay Characteristics of Nest Trees

Wood chips collected from current nest excavations in one coast redwood, one California black oak, one madrone, one red fir, seven ponderosa pines, and nine white firs all revealed fungal infection and decay. Excavation chips from a living giant sequoia and the previously described coast redwood showed no evidence of decay or fungal infection under microscopic examination.

Chips excavated by pileated woodpeckers from undecayed softer woods were comparable in hardness to chips from harder woods that had undergone decay (Table 1). Specific gravity of wood chips from dead ponderosa pine and western larch (*Larix occidentalis*) trees used by pileated woodpeckers for nest cavities was tested by Bull (1975). She calculated a mean specific gravity of 0.34 for dead

and decayed ponderosa pine and western larch, comparable to specific gravities of 0.30, 0.32, and 0.34 for green coast redwood, black cottonwood, and quaking aspen respectively (Markwardt and Wilson 1935).

Decay patterns were patchy on nest trees used by pileated woodpeckers (Fig. 1). Decay characteristics around the nest cavity were not the same as those at breast height, nor was decayed wood distributed in continuous columns for the five white firs and three ponderosa pines examined.

Cavity chambers were excavated through decayed heartwood. Chamber shapes followed the

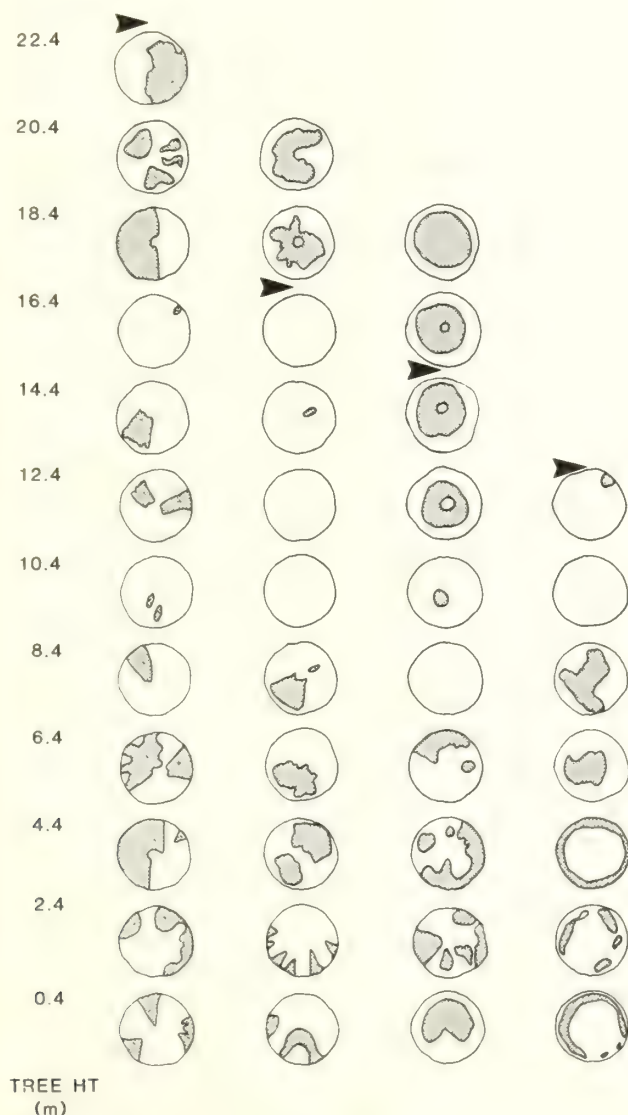


Figure 1.—Illustration of decay patterns (cross hatching) on three horizontally cross-sectioned ponderosa pine snags and a white fir [third from left], Eldorado County, Calif., used by pileated woodpeckers for nesting. Solid black arrows indicate nest hole height. (Diameters are not drawn to scale.)

configuration of decay in the heartwood. Three of the eight cavities showed evidence of insect galleries around entrance holes and corridors. Sapwood surrounding the nest cavities of all eight felled trees was sound by the knife test and visual inspection. Of the nest trees that had fallen by natural causes, none had broken at the level of the nest cavity, attesting to the relative strength of the sapwood surrounding the cavity.

DISCUSSION

Apparently sound and even green wood of softer tree species was used before decay had set in. In tree species with wood harder than coast redwood, black cottonwood, or quaking aspen, nest cavities were excavated by pileated woodpeckers after the heartwood had been softened by decay.

Broken tops, even on live trees, may serve as entry courts for heart rot fungus (Bega 1978). The high incidence of pileated woodpecker nest trees with broken tops suggests the birds may select for broken topped ones because of their decay characteristics.

Sound sapwood around the cavity chambers provides structural support for the nest and may make it less susceptible to predators (Kilham 1971, Conner 1977). Regardless of tree species, no nest snag was soft or rotten from advanced decay. Such trees apparently cannot support the large nest cavities of pileated woodpeckers. Mean and standard error for 7 nest chambers were 24.0 ± 1.1 cm by 40.3 ± 1.9 cm (Harris 1982). Old white fir snags were not used by pileated woodpeckers, as these less resinous and, therefore, less decay resistant tree species (Cline et al. 1980) either became too soft to be usable or fell down and became unavailable.

Insect galleries around some nest hole entrances and corridors suggest pileated woodpeckers may first use the future nest snag as a foraging site or that insect activity through the otherwise sound sapwood facilitates excavation by the woodpeckers. Neither hypothesis is mutually exclusive.

Areas of fungal decay on nest trees were patchily distributed. Because most Pinaceae snags used by pileated woodpeckers in this study were young or moderate-aged, fungal decay may not have had sufficient time to spread more continuously. In contrast, Conner (1978) in the southeast found decay spread throughout the heartwood in nest snags used by most woodpecker species. Miller et al. (1979) in the northwest reported extensive decay columns in most woodpecker nest trees. In both these studies, trees with extensive decay were used by woodpecker species less well adapted for excavating hard wood than the pileated (Burt 1930).

Managing for Pileated Woodpeckers

Pileated woodpeckers appear to choose a nest cavity site on the basis of the structural quality of the wood, particularly hardness, and not merely the fact that the tree is dead. Creating snags by topping, girdling, fungal inoculation, or silvicide treatment has been suggested to enhance cavity nesting bird habitat (Bull et al. 1980). I would

not recommend creation of snags by artificial means because the methods may not usually achieve the requisite decay conditions for pileated woodpecker nest trees.

Topping may create entry courts for fungus. Fungal inoculation along with topping may lead to the requisite decay characteristics. Girdling and silvicide treatments might not lead to heart rot (Evans and Conner 1979, Miller and Miller 1980), which typically initiates infection of the tree when alive (Bega 1978). Most importantly, Conner et al. (1981) suggested that trees killed by silvicide fall within 3 to 4 years, resulting in a net loss of snags several years after treatment, compared to an unmanipulated situation.

Forest rotation periods suitable for the maintenance of pileated woodpecker nesting habitat should be calculated on the basis of how long it takes to grow trees with characteristics needed by the species for nesting under local edaphic and climatic conditions. Conner (1978) recommended that stands of largely hardwoods used by pileated woodpeckers should have minimal 150 year rotations to allow time for decay to spread in potential nest trees. In California, however, pileated woodpeckers will use Pinaceae trees less than 75 years old with isolated patches of decay (Harris 1982).

Because pileated woodpeckers do not use soft or rotted snags, it is necessary to reserve sufficient numbers of "hard" snags and to provide for future recruitment of such snags. Most snags fall in winter storms, which vary in strength and frequency. What appears to be a sufficient supply of snags to maintain pileated woodpeckers in a period of "normal" winters may prove insufficient after a particularly severe winter with exceptional wind-fall of snags.

ACKNOWLEDGEMENTS

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Snag Use by Selected Raptors¹

Richard L. Glinski²

Teryl G. Grubb³

Larry A. Forbis⁴

Abstract.--As exemplified by the osprey, bald eagle and Mississippi kite, snag use by raptors is variable and includes nesting, resting and hunting. The concept of a snag should be expanded to encompass opportunistic snag use by raptors. Research and management is needed to preserve snags in southwestern riparian deciduous forests.

INTRODUCTION

Few studies have documented the importance of snags to specific raptors. Snag use by birds of prey is diverse and involves perching to rest or hunt, and nesting on exposed limbs or in cavities. The purpose of this paper is to provide insight on raptor use of snags by presenting information on three selected species: the osprey (Pandion haliaetus), bald eagle (Haliaeetus leucocephalus) and Mississippi kite (Ictinia mississippiensis). The data presented does not discuss every population of these species, but it exemplifies the variety of snag structures used by raptors and the management implications of snag use.

Birds of prey are usually opportunistic in their use of available resources, and their use of snags adheres to this tendency. Also, snag use varies among species. Ospreys usually nest in large dead conifers, but under local conditions they will nest on rock pinnacles, large columnar cacti or man-made structures that meet certain criteria. Bald eagles use snags extensively for perching to rest and hunt, and at times for nesting. Mississippi kites commonly forage from snags over areas of favorable prey densities, and often their snag perches consist of minute dead sprigs atop a live tree.

It is incorrect to assume that raptors that nest in snags are more dependent on snag habitat than those that perch or hunt from snags, especially since opportunism will often mask snag use. Nests are constantly used during a breeding season and can be readily discovered, but perches are temporarily used and their importance can be quantified only with more intensive research.

By demonstrating the diversity of snag use by selected raptors, we hope to broaden the concept of a snag. A snag is frequently defined as any dead standing tree (USDA 1978). For cavity nesting species, Evans and Connors (1978) defined a snag as a standing dead or partially dead tree, and Connor (1978) termed a snag as any dead, dying or living tree suitable as a nest site for a cavity nesting bird. Indeed, the process of a live tree dying is often a continuum rather than an abrupt event, with dead sprigs, limbs, and cavities existing in canopies of trees long before they are dead. Many deciduous trees, like cottonwoods (Populus fremontii), provide both dead and live nesting, foraging and resting substrate in a single tree. In addition, during winter deciduous trees assume leafless, snag-like characteristics that can be important for species like wintering bald eagles.

SNAG USE BY SELECTED RAPTORS

Snag Use By Ospreys

Throughout their range ospreys prefer nesting in snags (Table 1). Nest snags in California pine forests are generally prominent structures that exist in open tree stands with sparse overstory (Gale and Forbis 1974). Nearly all nests are placed at the top of a snag or snag-like structure rather than on lateral branches. In Florida, Szaro (1972) concluded that nest heights in the intertidal areas are determined by the heights of available dead black mangrove (Azicenna nitida).

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²Richard L. Glinski is a Regional Wildlife Specialist, Arizona Game and Fish Dept., Mesa, AZ, 85205.

³Teryl G. Grubb is a Research Wildlife Biologist, U.S.D.A. Forest Service, Rocky Mnt. Forest and Range Exper. Sta., Tempe, AZ 85287.

⁴Larry A. Forbis is a Forest Wildlife Biologist, Tonto National Forest, Phoenix, AZ 85038.

Table 1.--Habitat characteristics of four nesting osprey populations in the United States.

Locations (number of nests)	Percent of Nests in Snags	Preferred Nest Tree Species (percent preference)	Distance of Nest from Water	References
Oregon (63)	81	Lodgepole Pine (<u>Pinus contorta</u>) (67)	<400m (1300 ft) (76% of nests)	Roberts (1970)
Florida (47)	78	Black Mangrove (92)	(intertidal)	Szaro (1972)
Idaho (127)	80 ¹	----	<500m (1640ft) (53% of nests)	Van Deale et al. (1980)
Northern California (61)	93 ²	Douglas-Fir (<u>Pseudotsuga</u> <u>menziesii</u>) (87)	<92m (300ft) (85% of nests)	Gale and Forbis (1974)

¹Includes power poles and artificial platforms that present a situation similar to a snag.

²Includes spike-tops (live trees with dead tops).

Osprey management involves intensive snag management. Gale and Forbis (1974) suggested retaining all snags 38cm (15 inches) in diameter and 12m (40ft) tall in osprey nesting areas, and large live trees every 250m (820ft) as future replacement snags. Van Deale et al. (1980) recommended leaving live trees near snags to prevent wind damage of snags. Roberts (1980) documented the halt of an ongoing snag-clearing program in Oregon because of osprey nesting concerns. His management plan called for a 61m (200ft) "no logging zone" adjacent to water, a 341m (1120ft) "restricted-cutting zone," and retention of all snags and two dominant green trees in the restricted zone. Where necessary, snags can be created by killing live trees (Gale and Forbis 1974, Roberts 1970). Artificial snags for osprey nesting can also be created in selected locations using artificial structures (Van Deale et al. 1980, Gale and Forbis 1974, Roberts 1970, Kahl 1971 and 1972, and Johnson and Melquist 1973).

Snag Use By Bald Eagles

Snag use by bald eagles is as opportunistic as the species' foraging and nesting habits. Comparative size, abundance and location of trees are more important for nesting than absolute tree size or tree species. Topography and surrounding habitat vary with the activity, but perching, roosting and nesting usually occur in forested habitat along major lakes, rivers, or marine coastlines. Use-trees must have sturdy branching at sufficient height to support the nest, and good visibility and accessibility as provided by exposed branching, an open crown, crown dominance or tree isolation. Snags are frequently used, especially for perching, whenever they are present within the eagles' nesting or wintering habitat.

Stalmaster and Newman (1979), using a perch-preference index based on the ratio of utilization to availability, found that bald eagles strongly preferred dead trees for daytime perches. Relative height and morphological characteristics of the perch tree, range of vision from the perch, unobstructed flight paths, and proximity to water, feeding sites and open areas were contributing factors. Grubb and Kennedy (1982) also have documented a preference for daytime use of snags in the Southwest. In a continuing study near Stoneman Lake, Arizona, snags comprise less than 10 percent of the standing timber, but of 164 documented perch observations of 5-15 bald eagles, 65 percent were in dead or dead-topped trees. Most perches were in ponderosa pine (Pinus ponderosa) trees on a hillside above the lake and scattered in the pinyon-juniper upland, usually in the vicinity of foraging areas.

Limited winter roost data for the Southwest (Grubb and Kennedy 1982) suggest that some snags are usually present among the high-use trees within small, protected ponderosa pine stringers. Presumably these trees are used for roosting in milder weather, or by subordinates unable to compete for more protective live trees. They may also serve as sentinal perches during evening entry into the roost, when a bird on such a perch indicates the area is undisturbed to approaching eagles (Ingram and Koller 1981).

During the breeding season eagles favor snags for hunting and loafing perches, and for guard perches overlooking the nest site. Snags are particularly important near foraging areas, but are rarely selected as nest trees. In western Washington only 12 (6 percent) of 218 nests surveyed were in snags (Grubb 1976). In addition, the more decadent the tree the more likely a nest was to be inactive. In Arizona between 1977 and 1983, 19 of 71 nesting attempts have been in trees, of which 7 (or 10 percent of total nesting

attempts) were in snags.

One pair of breeding bald eagles in Arizona has consistently selected willow (*Salix* sp.) snags for nesting. These trees become suitable for eagle use only after they are dead and aged so that the restrictive fine branches have fallen away. However, such decadent condition has caused consistent loss of the nests or nest trees, so a permanent artificial "snag" in the form of a tripod was built in 1977 (Grubb 1980). Fortification of dead nest trees is another management alternative to reduce potential loss, as is relocating nests in live trees nearby. The removal of unsound, dead nest trees or at least the dead nest supporting portions is a legitimate alternative to avoid the risk of loosing active snag nests, but such action should be evaluated on a case by case basis.

Snag Use By Mississippi Kites

The Mississippi kite locally breeds in the southern United States from Florida through Arizona, nesting in live trees along drainages or in shelterbelts (Parker and Ogden 1979). The principle foraging strategy of this kite has been described generally as soaring and aerial pursuit of insects (Sutton 1939, Skinner 1962, Fitch 1963) Glinski and Ohmart (1983a) found that in Arizona, Mississippi kites captured 41 percent of the nestlings' diet (insects, mainly cicadas) by hawking (locating prey from perches) from snags within 150m (490ft) of the nest. Kites perched 10 to 20m (33-66ft) above the ground on dead branches of cottonwood trees. Kites employed this foraging strategy especially during morning and late afternoon periods when thermals and winds were not available to assist in soaring.

At two nesting sites where foraging behavior was intensively observed the hunting snags were on trees with less than 25 percent canopy die-out (44 percent), trees with 25-50 percent canopy die-out (37 percent), and trees that were half or totally dead (19 percent). Many of the cottonwoods with less than 25 percent canopy die-out appeared to be healthy trees, and some of these trees have sustained 10-20 percent canopy die-out from 1975 through 1983 (Glinski, pers. obs.). The spatial arrangement of cottonwoods around a kite nest is critical to kite reproduction, and the variation of vegetation structure (horizontal and vertical) surrounding nest trees accounted for 71 percent of the variation in nesting success (Glinski and Ohmart 1983a).

The importance of vegetation structure and snag perches to Mississippi kites in other areas of their breeding range is undocumented. These nest site components may be most operative for kites in Arizona since the breezes that may enhance aerial foraging and are typical of kite nesting areas in the Great Plains are usually absent or reduced in central Arizona riparian habitats, particularly at the time when kites are feeding nestlings.

The optimum kite habitat in Arizona is cottonwood-salt cedar (*Tamarix chinensis*) association. Although salt cedar generally will displace cottonwood (Robinson 1965), the vegetation associated with kite nesting areas in Arizona appears to be in the transition period when salt cedars are attaining heights of 3-8m (10-26ft) and when cottonwood trees 10-20m (33-66ft) are dying and providing snag perches. Salt cedar provides excellent habitat for the cicadas on which kites prey (Glinski and Ohmart 1983b), and the presence of cottonwoods with numerous snag forage perches protruding above the salt cedar presently combines to make certain riparian habitats in the Southwest excellent habitat for the Mississippi kite. Levy (1971) first documented the Mississippi kite in Arizona in 1970, and records for New Mexico began in 1950 (Parker and Ogden 1979). The recent occurrence of this kite in the Southwest may well coincide with the invasion of salt cedar and the initial stages of cottonwood degeneration, and thus with the development of favorable prey and foraging habitat.

CONCLUSIONS AND RECOMMENDATIONS

Snag use by raptors involves nesting, foraging and resting activities which, for most species, have not been sufficiently quantified to prescribe snag management guidelines. The definition of a snag needs to be expanded to encompass opportunistic snag use by raptors.

Ospreys commonly nest in prominent snags in open tree stands, and on artificial snags that retain similar features. Snag management for ospreys involves preserving snags, creating snags by killing live trees, and reserving living trees for future creation of snags. These management techniques are particularly applicable in pine habitats where large trees are common.

Bald eagles commonly perch and occasionally nest in snags. Throughout their breeding and wintering habitat, maintenance of existing snags and long-term provision for continued snag availability is an important management objective for bald eagles, particularly in foraging and loafing areas. Creation of snags or the construction of artificial snags also offers management potential for supplementing marginal habitat or redirecting eagle use away from disturbed areas.

The Mississippi kite in Arizona forages from snag perches. Its dependence on snags is not obvious since kite snag perches are often a dead sprig or limb in the canopy of a living tree. In the Southwest, many riparian deciduous trees provide snag habitat (dead limbs and cavities) throughout much of their lives, and thus to manage for broadleaf riparian snags generally is to manage for regeneration and maintenance of riparian trees. This effort will likely require a greater commitment than the maintenance of pine snags since more ecological factors are involved with riparian plant succession (Johnson et al. 1977). As the salt cedar-cottonwood association degrades to a salt cedar monoculture and cottonwood nest trees and snag perches are eliminated,

the kite population in the Southwest will likely decline. The potential for riparian deciduous trees in the Southwest to afford snag habitat for raptors will likely diminish as plant succession occurs in degraded river bottoms. Intensive research and management techniques are needed to preserve riparian deciduous snags.

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Snag Use by Birds in Douglas-fir Clearcuts¹

Bruce G. Marcot²

Abstract.--In Douglas-fir (*Pseudotsuga menzeisii*) clear-cuts in northwestern California, bird species richness (mean number of species) and detection rates (mean number of birds of all species recorded per 10-minute count) were significantly greater in grass/forb and early brush/sapling stages where snags were present compared to where snags were absent. Mean detection rates and percent occurrence at count points of five primary and four secondary cavity nesters were significantly greater in clear-cuts with snags compared with clear-cuts without snags during breeding and post-breeding seasons. An exception was chestnut-backed chickadee (*Parus rufescens*). Most cavity-nesting species probably nested in adjacent, forested stands and used the clear-cuts for foraging.

INTRODUCTION

Forest management practices associated with harvesting timber, such as cutting, hazard reduction, and such site preparation methods as burning and mechanical disturbance cause the loss of snags. Over a rotation cycle, numbers of snags, especially large snags, will decline from these practices operating in concert over a large forest area undergoing intensive silvicultural treatment.

One effect of long-term declines in snag densities has been documented as declines in populations of hole-nesting birds (Haapanen 1965, Conner et al. 1975, McClelland and Frissell 1975, Bull and Meslow 1977, Scott 1979). For example, in Finland, Haapanen (1965) found that the density of hole-nesting birds decreased by 44 percent when large snags were eliminated from managed forests. Similarly, in Arizona, Scott (1979) reported that in ponderosa pine (*Pinus ponderosa*) habitat where conifer snags were removed during a timber harvest, bird population densities decreased 27 percent and hole-nesting bird densities decreased 51 percent, while population densities increased in unharvested, adjacent control plots and harvested plots where snags were retained.

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² Bruce G. Marcot is a Research Assistant with Oregon Cooperative Wildlife Research Unit, Department of Fisheries and Wildlife, Oregon State University, Corvallis, Ore.

To provide a basis for managing snags during timber harvest, relationships of snag distribution and density to faunal distribution and abundance in early successional stages should be documented. The objective of this paper is to compare count frequency and occurrence of bird species in Douglas-fir (*Pseudotsuga menzeisii*) clear-cuts where snags had been retained and where snags had been removed during timber harvest.

STUDY AREA AND METHODS

Thirty-seven Douglas-fir clear-cuts, representing recent forest management practices, were selected in the Six Rivers and Shasta-Trinity National Forests in northwestern California. Three growth classes were represented (Table 1): 1) grass/forb (less than 20 percent woody vegetation cover, brush generally under 1 m in height), 2) early brush/sapling (over 20 percent woody cover, brush generally under 3 m in height), and 3) late brush/sapling (dense woody cover, brush generally over 3 m in height). The clear-cuts had been burned, planted with seedling Douglas-fir, and, except for the grass/forb stage, sprayed with herbicides (2,4-D or 2,4,5-T). The predominant cover on most of the clear-cuts was species of brush and broad-leaf hardwoods, including bull thistle (*Cirsium vulgare*) and berries (*Rubus* spp.) in the grass/forb stage, and mountain whitethorn (*Ceanothus cordulatus*), deerbrush (*C. integriramus*), tobacco brush (*C. velutinus*), canyon live oak (*Quercus chrysolepis*), tanoak (*Lithocarpus densiflora*), blue elderberry (*Sambucus caerulea*), Pacific madrone (*Arbutus menziesii*), and gooseberry (*Ribes* spp.) in the

Table 1.--Characteristics of the Douglas-fir (*Pseudotsuga menzeisii*) clear-cut study plots, northwestern California. Data are means with ranges in parentheses.

Growth stage	Stand size (ha)	No. bird count points	No. years since activity (as of summer 1981)			
			Cutting	Burning	Planting	Spraying ¹
Grass/forb (13 plots)	9.3 (5-17)	14	5 (13 plots) (3-9)	3 (11 plots) (1-5)	2 (13 plots) (0-3)	(0 plots)
Early brush/sapling (10 plots)	17.8 (11-25)	15	13 (10 plots) (6-21)	9 (8 plots) (2-14)	9 (10 plots) (4-19)	5 (5 plots) (1-7)
Late brush/sapling (14 plots)	17.5 (9-25)	23	15 (14 plots) (5-19)	14 (5 plots) (5-18)	14 (14 plots) (3-18)	7 (11 plots) (5-10)

¹Aerially-applied herbicides (2,4-D or 2,4,5-T) for brush control.

brush/sapling stages. Some of the late brush/sapling stage clear-cuts contained planted ponderosa pine or naturally seeded white fir (*Abies concolor*).

Topographic characteristics of the clear-cuts were taken from orthographic-photo maps (scales 1:12,000 or 1:24,000) or from on-site measurements (percent slope).

Vegetation was measured around each count point by placing each of three 2 x 30 m belt transects at random distances between 18 and 90 m from the count point. Compass direction from the count point to the first belt was chosen randomly, and the other two belts were then located at increments of 120°. Within each belt, plant height and foliage volume were measured using the HTVOL procedure of Mawson et al. (1976), which entails visually estimating plan and profile shapes of each plant's foliage *en masse*, measuring foliage depth and breadth, and computing overall volumes.

Along one edge of each 30 m belt, down wood was measured and weights of woody debris of all sizes were estimated using the procedure of Brown (1974).

Fifty-two bird count points were positioned centrally in the clear-cuts, 13 in clear-cuts where snags were absent and 39 in clear-cuts where snags were left during harvest. A snag was defined as any standing dead tree at least 10 cm in diameter at breast height and at least 1.8 m tall (Thomas et al. 1979). Two count points were used in some of the larger clear-cuts, but the points were positioned at least 360 m apart or were separated by a ridge. A total of 2580 ten-minute bird counts were conducted: 468 at points where snags were present and 132 at points where snags were absent, during spring and breeding seasons (12 March to 16 June 1982); and 1500 at points where snags were present and 480 at points where snags were absent, during summer and fall seasons (6 August to 18 November 1981 and 17 June to 3 November 1982).

Where present, snag densities ranged from about 2 to 10 per ha within 200 m of the count point. Snags were mostly Douglas-fir, Pacific madrone, or tanoak. All snags were generally in early stages of decomposition, i.e. characterized by relatively sound wood with at least some of the bark intact (Thomas et al. 1979) and ranged in height from 1.8 to 60 m. Snags were located in the center portions of the clear-cuts either as scattered individuals or, less often, in groups of ten to fifty.

RESULTS

Topographic and vegetation characteristics at bird count points where snags were left did not differ significantly from characteristics at points where snags were absent (unpaired t-tests, all $P > 0.05$), except for percent occurrence of live residual trees (Table 2). Generally, when snags were left during timber harvest, so were scattered live residual trees in densities roughly equal to those of snags.

The average number of all bird species observed at count points in clear-cuts with snags did not differ significantly from the number observed in clear-cuts without snags, when growth stages and seasons were combined (Table 3). However, average detection rates of all bird species combined were significantly higher in clear-cuts with snags compared with clear-cuts without snags. Differences in average number of bird species and detection rates in clear-cuts with snags compared with clear-cuts without snags were significant in grass/forb and early brush/sapling stages and were insignificant in the late brush/sapling stage.

Mean detection rates of the six primary and four secondary cavity-nesting species observed during counts were consistently greater in clear-cuts with snags compared with clear-cuts without snags (Table 4). This was true in both seasons tested (Wilcoxon's signed-ranks test, $P = 0.05$), with two exceptions: pileated woodpecker (scientific names in Table 4), which was not observed during spring and breeding seasons, and chestnut-backed chickadee.

Table 2.--Topographic and vegetation characteristics at bird count points in Douglas-fir clear-cuts with and without snags.

Characteristic	Clear-cuts with snags		Clear-cuts without snags	
	Mean	S.D.	Mean	S.D.
Elevation (m)	1060	142	1045	147
Size (ha)	15.2	5.5	15.1	6.4
Slope (%)	46	19	50	21
Aspect (% of total)				
N (315-45°)	54		52	
E (46-135°)	16		19	
S (136-225°)	6		7	
W (226-315°)	25		21	
No. plant species over 10 cm tall	18	6.5	25	11.2
Percent count points with live residual trees	95		23**	
Total foliage volume (m ³ /ha)	8407	9378	6474	6141
Brush height (m)	4.4	2.9	3.8	2.6
Down wood (metric tons/ha)	94.7	57.8	62.6	41.0

** Significantly different ($P < 0.001$, Chi-square test).

Percent occurrences at count points of these same 10 species were the same or greater in clear-cuts with snags compared with clear-cuts without snags in at least one of the two seasons tested (Table 4). In particular, percent occurrence of red-breasted sapsucker, hairy woodpecker, house wren, Bewick's wren, and western bluebird were significantly greater in clear-cuts with snags compared with clear-cuts without snags during spring and breeding seasons. Other species showed the same trend during summer and fall seasons. Again, the exception was chestnut-backed chickadee, which showed a marginally, significantly greater percent occurrence in clear-cuts without snags during spring and breeding seasons and no difference during summer and fall seasons.

DISCUSSION AND MANAGEMENT IMPLICATIONS

The use of comparative, observation data to infer a causal link between snag presence in clear-cuts and distribution and abundance of birds raises several important considerations.

First, the presence of snags did not seem to bias the bird counts by increasing the likelihood of birds being seen. Twenty-two percent of a subsample of 19,282 observations of all bird species in all seasons from count points where snags were left, and 26 percent of a subsample of 4,940 observations from points where snags were removed, were recorded as "seen" rather than "heard only". The percent "seen" was also not significantly different (chi-square tests, $P > 0.05$) between count points where snags were left and where snags were removed when observation subsamples were stratified by season or by any of the species presented in Table 4.

Second, the presence of factors other than snags at count points may have influenced distribution

and abundance of bird species. Yet, aside for snag presence, Table 2 suggests no factor to serve at least as a working hypothesis to account for differences in detection rates and percent occurrence of cavity-nesting bird species, except for presence of live residual trees. Indeed, a number of the cavity-nesting species were observed using live trees for perches. Average detection rates of the cavity-nesting species in clear-cuts where live residual trees were present showed similar patterns as with snags present and absent. However, percent occurrence of some bird species at count points with and without live residual trees showed different patterns than percent occurrence of bird species at count points with and without snags (Table 4). That is, snags and live trees may relate differently to the distribution of some bird species in clear-cuts. In both seasons surveyed, detection rates (Wilcoxon's signed-ranks tests, $P < 0.05$) of all cavity-nesting species were significantly less at count points where live residual trees were retained and snags were removed than at count points where both live residual trees and snags were retained. This, again, suggests a relation between snag presence and distribution and abundance of cavity-nesting species.

All the cavity-nesting species were observed to use snags in clearcuts for perching, and many were observed using snags for foraging. Observations of nests were incidental. Most of the cavity-nesting species probably nested in nearby uncut stands and used clear-cuts as foraging habitat, such as reported by Morrison and Meslow (1983) in Coast Range clear-cuts of Oregon.

All the primary and secondary cavity nesting species observed in this study, except pileated and acorn woodpeckers, are known to nest in Douglas-fir cut-over areas (Hager 1960, Mannan et al. 1980, Morrison and Meslow 1983), although

Table 3.--Number of bird species detected at count points and detection rates (number of birds of all species recorded per 10-minute count) in Douglas-fir clear-cuts, 6 Aug 1981 to 3 Nov 1982, excluding the winter period 19 Nov 1981 to 11 Mar 1982.

Growth stage	Clear-cuts with snags			Clear-cuts without snags			Significance level ¹
	Mean	S.D.	N	Mean	S.D.	N	
NUMBER OF BIRD SPECIES ²							
Grass/forb	13.7	4.3	29	10.8	3.2	9	0.07
Early brush/sapling	21.7	5.4	49	19.3	4.9	25	0.07
Late brush/sapling	20.5	5.9	73	20.2	5.7	17	0.49
All	19.6	6.2	151	18.1	5.9	51	0.14
DETECTION RATES ³							
Grass/forb	12.26	7.31	372	8.20	7.66	108	<0.001
Early brush/sapling	16.33	6.35	564	11.84	3.96	300	<0.001
Late brush/sapling	13.53	6.07	876	13.49	5.30	204	0.18
All	14.14	6.57	1812	11.75	5.40	612	<0.001

¹Unpaired t-test.

²N = no. of plot-censuses. A plot-census consisted of 12 ten-minute counts at each point.

³N = no. of 10-minute counts.

Morrison and Meslow (1983) reported very low breeding densities of cavity nesters in their clear-cut study plots. Species-specific studies of bird foraging, nesting, and roosting may reveal more direct relationships between bird populations and snags in clear-cuts. For example, Brawn et al. (1982) reported that snags were important winter foraging substrates for cavity nesters in oak-hickory forest.

Snag blowdown occurred during winter in some upper-slope and ridgetop clear-cuts in this study. On one clear-cut, all (several dozen) snags in one centrally located patch were reduced two-thirds in height from blowdown. Scott (1978) noted that about 30 percent of ponderosa pine snags were lost during timber harvest and 34 percent after harvest to subsequent logging, blowdown, or fuel wood cutting. When clear-cutting, additional snags and defective trees may be retained to offset such losses.

Care should be taken during site-preparation following clear-cutting not to disturb residual

trees and snags. When burning, woody debris may first be cleared away at least 6 m from the base of snags or trees, as charring greatly reduces the quality of wood for nest excavation and foraging use by birds (e.g., Maser et al. 1979).

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Table 4. Abundance and distribution of cavity-nesting bird species in Douglas-fir clear-cuts in northwestern California during spring and breeding (Sp + B) and summer and fall (Su + F) seasons.

Species	Season	Detection rate (mean no. observed per count)		Percent occurrence (at count points)			
		with snags	without snags	with snags	without snags	with trees	without trees
Primary Cavity Nesters							
Northern flicker (<i>Colaptes auratus</i>)	Sp + B	0.13	0.11	44	45	44	45
	Su + F	0.16	0.09	64	50*	62	55
Pileated woodpecker (<i>Dryocopus pileatus</i>)	Sp + B	0.00	0.00	0	0	0	0
	Su + F	0.007	0.004	6	3+	6	3+
Acorn woodpecker (<i>Melanerpes formicivorus</i>)	Sp + B	0.04	0.02	13	18	10	27**
	Su + F	0.18	0.02	28	18*	26	23
Red-breasted sapsucker (<i>Sphyrapicus ruber</i>)	Sp + B	0.08	0.01	26	9**	23	18
	Su + F	0.02	0.01	9	5+	9	5+
Hairy woodpecker (<i>Picoides villosus</i>)	Sp + B	0.02	0.01	15	9*	15	9*
	Su + F	0.03	0.01	17	5**	17	5**
Chestnut-backed chickadee (<i>Parus rufescens</i>)	Sp + B	0.08	0.11	33	45+	33	36
	Su + F	0.22	0.28	55	60	56	58
All primary cavity nesters							
Total	Sp + B	0.35	0.26				
	Su + F	0.62	0.41				
Average	Sp + B	0.06	0.04				
	Su + F	0.10	0.07				
All woodpeckers							
Total	Sp + B	0.27	0.15				
	Su + F	0.40	0.13				
Average	Sp + B	0.05	0.03				
	Su + F	0.08	0.03				
Secondary Cavity Nesters							
Violet-green swallow (<i>Tachycineta thalassina</i>)	Sp + B	0.002	0.00	3	0+	3	0**
	Su + F	0.29	0.10	14	8*	12	13
House wren (<i>Troglodytes aedon</i>)	Sp + B	0.82	0.55	64	36**	64	36**
	Su + F	0.20	0.12	40	30+	38	38
Bewick's wren (<i>Thryomanes bewickii</i>)	Sp + B	0.11	0.03	36	18**	33	27
	Su + F	0.08	0.03	28	18*	26	23
Western bluebird (<i>Sialia mexicana</i>)	Sp + B	0.18	0.05	38	9**	36	18**
	Su + F	0.16	0.11	30	20*	26	33
All secondary cavity nesters							
Total	Sp + B	1.11	0.63				
	Su + F	0.73	0.36				
Average	Sp + B	0.28	0.16				
	Su + F	0.18	0.09				

¹ Chi-square test of difference of percent occurrence.

+ 0.05 < P < 0.10

* 0.01 < P < 0.05

** P < 0.01

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Snags as Indicators of Habitat Suitability for Open Nesting Birds¹

John M. Marzluff² and L. Jack Lyon³

Abstract.--The habitat requirements of open nesting birds were examined in 19, five hectare, plots arranged along an altitudinal gradient in western Montana. Seven, mature forest birds were examined in detail. Percent shrub and low canopy cover (0.5-1.5m), mid-canopy cover (8-25m), and the number of large diameter stems (25-50 cm dbh) were of major importance to this avian community. Increased avian diversity was associated with increased structural complexity of plots. Precise habitat recommendations for each species are proposed and related to more easily quantified snag variables. Management of western Montana forests to sustain production of 80 snags per hectare, preferably in a clumped distribution, will provide suitable habitat not only for cavity nesters, but also for sensitive open nesting species.

INTRODUCTION

That avian community structure and density of individual species respond to vegetative characteristics is well known (For example, Balda 1975, Anderson 1979, James and Wamer 1982). This response is commonly quantified by observing changes in the avian community following concomitant changes in vegetation through successional stages (Anderson 1979, Smith and MacMahon 1981), or in response to timber harvesting (Hagar 1960, Kilgore 1971, Webb et al. 1977). Such studies have shown that although avian biomass may remain constant following habitat alteration, species composition changes drastically. In addition, structural, not taxonomic characteristics of the vegetation are the primary determinants of avian communities and populations (MacArthur and MacArthur 1961, James 1971, Roth 1976). Yearly abiotic fluctuations, however, may reduce the direct response of the avian community to the plant community (Stamp 1978).

Use of multivariate statistical techniques to examine numerous habitat measurements simultaneously has greatly added to our knowledge of bird species habitat requirements. In general, these studies also support the importance of habitat structure. Specifically, combinations of variables such as percent canopy cover, canopy height, number of tree species, and number of stems in smaller dbh categories (< 9 cm) have been found to influence avian communities (James 1971, Anderson and Shugart 1974, Whitmore 1975, Johnston 1979).

In comparison to other regions, relatively few studies have been conducted in the Rocky Mountains of Montana to determine habitat requirements of non-game birds (Manuwal 1968, McClelland and Frissell 1975, McClelland et al. 1978, Harvey and Weaver 1979, McClelland 1979, Ramsden et al. 1979). This information is crucial to the forest manager who, with it, will be able to weigh the effects of alternative management strategies on specific groups of birds. Our main objective is to precisely quantify the habitat requirements of seven open nesting birds. The species selected are primarily dependent upon mature old growth or riparian forests and hence are most susceptible to structural changes induced by timber management. In addition, we propose that snag counts and measures of snag basal area can be used as indicators of habitat suitability for these species. This technique, although indirect, is useful to managers since the measurement of appropriate percent cover and stem variables is tedious, imprecise, and costly.

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²Current address: Department of Biological Sciences, Northern Arizona University, Flagstaff, Arizona, 86001.

³Wildlife Research Biologist, USDA Forest Service, Forestry Sciences Lab, Missoula, Montana, 59806.

METHODS

Study Areas

Nineteen study plots were located in Lolo Creek drainage from Lolo, Montana to Lolo Pass along U.S. Highway 12. These sites included habitats varying from ponderosa pine (*Pinus ponderosa*) types at 1052m to Engelmann spruce (*Picea engelmannii*)-subalpine fir (*Abies lasiocarpa*) types at 1628m. Representative forest communities ranging from clear-cuts to old growth were selected on varying aspects. Three paired sets of riparian and upland sites were situated along the altitudinal gradient.

Field Methods

Birds were censused along line transects (Emlen 1971) laid out by compass in a rectangular pattern on each study plot. Each transect consisted of 20 segments, 25m in length, for a total transect length of 500m.

Birds were censused between a half-hour before sunrise and noon on days with reasonably clement weather during the interval June 15 to September 15, 1979. The observer walked slowly along the transect route recording all birds heard or seen within a belt approximately 50m on either side of the transect line. This provided for a total census area of 5 ha per study plot. A three minute pause every 25m allowed the observer to carefully scan the area thus increasing the probability that all birds would be detected. Each transect was censused five times through the course of the study. Bird species, distance from the transect line, height above the ground (if seen), and observation type (sight/sound) were recorded.

Vegetation data were taken on circular plots, 5.64m in radius (100m²), every 25m along the transect. This provided 20 samples per transect. Twenty habitat variables were measured in each plot (Table 1). Percent cover at each of the levels measured was assigned to one of the following cover classes: 0 = no cover, 1 = less than 5% cover, 2 = 5-25% cover, 3 = 25-50% cover, 4 = 50-75% cover, and 5 = 75+% cover. Absolute counts of live and dead tree stems and pieces of downed woody material and stumps in each of the plots were also recorded. The most abundant tree, shrub, and forb species were identified and noted. A 5 BAF prism was used to measure tree and snag basal area. The average value for each vegetation measurement per plot was used in subsequent analyses. In addition to these site data, average elevation and aspect for each 100m segment was recorded.

Statistical Procedures

Pearson correlation coefficients were computed for all first order combinations of variables. Multiple regression equations were generated by REX (Grosenbaugh 1967), a multivariate combinational screening program in

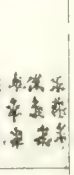
Table 1.--Habitat variables measured in each 100 m² plot.

1. Percent cover 0 to .5 meters
2. Percent cover .5 to 1.5 meters
3. Percent cover 1.5 to 2.5 meters
4. Percent cover 2.5 to 8 meters
5. Percent cover 8 to 25 meters
6. Percent cover 25+ meters
7. Number of live and dead stems less than 2 cm dbh
8. Number of live and dead stems 2 to 5 cm dbh
9. Number of live and dead stems 5 to 10 cm dbh
10. Number of live and dead stems 10 to 25 cm dbh
11. Number of live and dead stems 25 to 50 cm dbh
12. Number of live and dead stems 50+ cm dbh
13. Square meters of downed logs and stumps
14. Prominent tree species
15. Prominent shrub species
16. Prominent grass and forb species
17. Tree basal area
18. Snag basal area
19. Elevation
20. Aspect

which all possible linear combinations of 18 independent variables taken three at a time were screened for the best-fitting regression. All computer runs were performed on a Perkin-Elmer 3220 computer located at the Northern Forest Fire Lab, Missoula.

RESULTS

During the course of this 12 week study 6,000 birds of 73 species were recorded. Bird species diversity (MacArthur and MacArthur 1961) and the absolute number of bird species both increased in study plots of increasing structural complexity (Fig. 1). Mature riparian forests had twice the number of species and more than four times the avian diversity than did the structurally uniform plantation plot.

HABITAT	MATURE RIPARIAN FOREST	SELECTIVELY LOGGED PLOT	CLEARCUT PLOT	PLANTATION PLOT
				
H [*]	11.00	7.34	6.29	2.67
NUMBER OF SPECIES	14	12	11	7

$$H = \frac{1}{\sum p_i^2}$$

Figure 1.--The effect of habitat structural complexity on avian diversity.

Avian species composition also changed greatly between plots. Plantation and especially clear-cut plots were dominated by more typical open grassland species such as Vesper Sparrows (*Poocetes gramineus*) and Mountain Bluebirds (*Sialia currocoides*) or by species more general in their use of habitats, such as Yellow-rumped Warblers (*Dendroica audoboni*) and Pine Siskins (*Pinus spinus*). Conversely, mature spruce-fir and riparian areas, in addition to supporting a large number of siskins, supported many Golden-crowned Kinglets (*Regulus satrapa*), Townsend's Warblers (*Dendroica townsendii*), and Swainson's Thrushes (*Hyolcichla ustulata*). Fox Sparrows (*Passerella iliaca*), Warbling Vireos (*Vireo gilvus*), MacGillivray's Warblers (*Opromis tolmici*), and Wilson's Warblers (*Wilsonia pusilla*) also showed increased abundances in these mature forest areas. We will concentrate on these seven mature forest species.

High percent cover, especially at the 0.5m to 1.5m levels, was of major importance to Fox Sparrows and Wilson's Warblers. This cover, in conjunction with upper strata cover was also important to Townsend's Warblers. The other four species were more common in areas with many large trees or high percent canopy cover.

The ability to characterize each species' habitat requirements more specifically was variable (Table 2). Increasing abundance on plots with high shrub and low canopy (0.5-1.5m) cover, many large diameter (50+cm dbh) stems, and few stems less than 2 cm dbh accounted for 56% of the variation in Fox Sparrow abundance. Occurrence of

Swainson's Thrushes on high elevation plots with many 25-50 cm dbh stems and high snag basal area accounted for 82% of the variation in their numbers. Townsend's Warblers were primarily found on plots with high percent cover 8-25m above ground, high shrub and low canopy cover, and few large stems. These variables explained 63% of the variation in Townsend's Warbler abundance. Combining high elevation plots with high shrub cover and many snags with dbh greater than 30 cm accounted for 76% of the variation in Wilson's Warbler abundance. The reliance of Warbling Vireos on plots with high canopy (25+m) and upper (8-25m) stratum cover, and plots with low tree basal area explained 63% of the variation in their abundance. MacGillivray's Warblers appeared most dependent upon old growth stands since 91% of the variation in their abundance was accounted for by occupation of plots with many large (50+ cm dbh) stems, and many snags greater than 30 cm dbh. These warblers were also found on plots with *increasing* snag basal area, even though this variable is negative in the equation. Golden-crowned Kinglets were primarily found on plots with many large and medium diameter stems (25-50 cm and 10-25 cm dbh). This, in combination with increasing abundance on plots with high tree basal area, explained 75% of the variation in kinglet abundance.

The inclusion of snag variables in the regression equations of Swainson's Thrushes, MacGillivray's and Wilson's warblers is interesting since these species are not known to directly rely upon dead trees. The abundance of these species also had a strong positive

Table 2.--Predictive equations of individual species' habitat requirements.

SPECIES	EQUATION ^a	R ²
Fox Sparrow	$-1.80 + 1.17 (\%COV \ 0.5-1.5m) + 5.36 (STEMS \ 50+cm) - .081 (STEMS < 2cm)$	.56
Swainson's Thrush	$-21.39 + 4.18 (STEMS \ 25-50cm) + 6.59 (ELEV) + 1.04 (SNAG \ B.A.)$	.82
Townsend's Warbler	$-18.09 + 11.37 (\%COV \ 8-25m) + 10.26 (\%COV \ .5-1.5m) - 40.97 (STEMS \ 50+cm)$	.63
Wilson's Warbler	$-12.23 + 0.99 (\%COV \ .5-1.5m) + 8.18 (ELEV) + 2.74 (SNAGS > 30cm)$	.76
Warbling Vireo	$0.61 + 222.35 (\%COV \ 25+m) + 14.77 (\%COV \ 8-25m) - 1.43 (BASAL \ AREA)$	.63
MacGillivray's Warbler	$-1.45 + 61.43 (STEMS \ 50+cm) - 2.98 (SNAG \ BA) + 19.31 (SNAGS > 30cm)$	.91
Golden-crowned Kinglet	$0.16 + 28.47 (STEMS \ 25-50cm) + 7.49 (STEMS \ 10-25cm) - 2.43 (BASAL \ AREA)$	.75

^a Equations predict abundance in number of birds per 5 hectares

relationship with the measured snag variables (Table 3). Fox Sparrows and Townsend's Warblers also had moderately significant positive relationships with the number of 30+ cm dbh snags and snag basal area (Table 3). The abundances of Warbling Vireos and Golden-crowned Kinglets were not responsive to either snag variable, however, they tended to increase in plots with higher snag values. Townsend's Warblers and Golden-crowned Kinglets responded more to snag basal area, whereas, all other species were more responsive to snag numbers (Table 3).

The apparent reliance of these open nesting species on snags can be accounted for by examining the relationship of the snag variables to percent cover and stem variables. All correlations between the snag variables and cover or stem measures are positive, and 10 out of 24 are significant at $p < .10$ (Table 4). This indicates that as the number or basal area of snags increased so did the live cover and stem variables. Snag basal area was most directly linked to upper strata cover and stem variables, while the number of snags greater than 30 cm dbh primarily reflected shrub cover and the occurrence of large stems (Table 4).

Discussion and Management Recommendations

The major drawback of this study is that it represents data collected over only one year. In addition, the precise habitat used by individuals of a given species was not quantified. Instead, vegetation was sampled along the census transect irrespective of bird occurrence. Studies such as Johnston's (1977) in which the location of an individual bird was used as the center of the vegetation plot may quantify a species' specific habitat requirements more accurately, for example, by delimiting nesting and foraging habitat. These

types of studies can also discriminate habitat use in relation to species' annual cycles, whereas we provide only one measure of habitat use for the breeding season as a whole. In terms of avian community management, however, such precise documentation of habitat use may not be necessary because cost effective management practices are, as of yet, not exact enough to provide seasonally variable habitats for each stage of the annual cycle. Despite the apparent drawbacks of our study we generated highly predictive models of habitat requirements.

At the community level, the structural diversity of the habitat greatly influenced avian diversity. Similarly, avian density increased from plantation to managed to mature forest plots in southern Sweden (Nilsson 1979). In our study, even if density does not vary in accordance with structural complexity, avian species composition does. The more intensely managed plantation and clear-cut plots did hold viable bird populations, but they were composed of more typical grassland or generalist species, not in need of active management to ensure their prosperity. Conversely, the structurally complex mature forests not only supported a richer avian community, they supported a distinct avian community, composed of species with narrow habitat requirements that would be adversely effected by intensive timber management techniques. These results lead us to recommend habitats be managed for increased structural complexity. Special effort should be made to provide for substantial shrub, low canopy and mid-canopy cover development. This is in contrast to recommendations by Kilgore (1971) and Anderson (1979) stating that shrub cover is unimportant.

Our species specific habitat recommendations (Table 5) stress the importance of one or two

Table 3.--Relationship of bird abundance to snag variables.

SPECIES	NUMBER ^a	NUMBER OF SNAGS			SNAG BASAL AREA		
		r	N	P	r	N	P
Fox Sparrow	13	.550	19	.01	.272	19	NS
Swainson's Thrush	106	.405	19	.10	.358	19	NS
Townsend's Warbler	246	.233	19	NS	.369	19	.10
Wilson's Warbler	23	.600	19	.001	.336	19	NS
MacGillivray's Warbler	121	.724	19	.001	.375	19	.10
Golden-crowned Kinglet	241	.093	19	NS	.197	19	NS

^a Total number of sightings during study period

Table 4.--Relationship of percent cover and stem counts to snag variables.

VEGETATION MEASURE	SNAG BASAL AREA		NUMBER OF SNAGS	
	r	p ^a	r	p ^a
Percent Cover 25+m	.099	NS	.041	NS
Percent Cover 8-25m	.406	.10	.250	NS
Percent Cover 2.5-8m	.568	.01	.401	.10
Percent Cover 1.5-2.5m	.338	NS	.472	.05
Percent Cover .5-1.5m	.282	NS	.460	.05
Stems 50+ cm dbh	.348	NS	.618	.001
Stems 25-50 cm dbh	.242	NS	.347	NS
Stems 10-25 cm dbh	.494	.05	.084	NS
Stems 5-10 cm dbh	.637	.001	.238	NS
Stems 2-5 cm dbh	.514	.02	.308	NS
Stems < 2 cm dbh	.194	NS	.216	NS
Live Tree Basal Area	.547	.02	.254	NS

^a Sample size for all correlations is 19

plant characteristics. We must emphasize that although these are the characteristics of prime importance to each species, they alone do not constitute a given species' habitat. Instead, the recommended habitat must be maintained in conjunction with typical cover and stem counts in all strata of natural forests. In making the

following recommendations we have averaged the important habitat variables per bird species found on the three plots where the abundance of a given bird was highest. Therefore, we present vegetative attributes of the preferred habitat of each species.

Fox Sparrows and Wilson's Warblers were most dependent upon shrub and low canopy (0.5-1.5m) cover, preferring from 40% to 65% of this stratum covered. Wilson's Warblers primarily inhabited high altitude plots, and Fox Sparrows preferred the occurrence of large stems in addition to shrub cover. Swainson's Thrushes preferred high elevation plots with 170 live stems, 25-50 cm dbh, per hectare. Less extensive shrub and low canopy cover (25-50%) was important to Townsend's Warblers possibly because of the importance of upper (8-25m) stratum cover. This warbler prefers areas with 5% to 25% upper level cover, but we recommend providing the full 25% since we most commonly observed this species in the upper foliage. In accordance, Mannan and Meslow (1983) stressed the importance of grand fir (*Abies grandis*) canopy cover for Townsend's Warblers in Oregon. Townsend's Warblers were not dependent upon grand fir in our study but appeared more closely tied to Douglas fir (*Pseudotsuga menziesii*), thus pointing to the importance of structural not taxonomic characteristics of the vegetation in determining bird use. Warbling Vireos also preferred areas with 5% to 25% upper level cover and less than 5% canopy (25+m) cover. This preference for less than 5% canopy

Table 5.--Characteristics of species specific preferred habitat.

SPECIES	PREFERRED VEGETATION	SNAG CHARACTERISTICS	
		Basal Area ¹	Number ²
Fox Sparrow	40-65% cover .5-1.5 m 23 stems 50+ cm dbh/ha	2.92	87
Swainson's Thrush	High Elevation 170 stems 25-50 cm dbh/ha	2.92	87
Townsend's Warbler	25-50% cover .5-1.5m 5-25% cover 8-25m	1.39	17
Wilson's Warbler	40-65% cover .5-1.5m High Elevation	2.92	87
Warbling Vireo	< 5% cover 25+m 5-25% cover 8-25m	1.56	23
MacGillivray's Warbler	35 stems 50+ cm dbh/ha	10.93	101
Golden-crowned Kinglet	130 stems 25-50 cm dbh/ha 610 stems 10-25 cm dbh/ha	6.81	23

¹ m²/ha
² number/ha

cover is somewhat misleading, since none of our plots had over 5% canopy cover. MacGillivray's Warblers were most dependent upon the presence of large (50+cm dbh) stems, possibly reflecting the intercorrelation of this variable with shrub and low canopy cover. MacGillivray's Warblers were always observed in association with thick shrub cover in our study and by Morrison (1981). Golden-crowned Kinglets were not associated with low stratum cover, but instead preferred plots with 130 stems 25 to 50 cm dbh, and 610 stems 10 to 25 cm dbh per hectare. This is in accordance with our observations that kinglets primarily utilized upper foliage strata. In addition, this species was primarily confined to the upper elevation spruce-fir sites.

Taking the results for all species together, we can make a more holistic recommendation for maintaining populations of these species through the breeding season. The ideal site would provide 75% ground cover, 50% to 65% shrub cover, 25% cover 8 to 25m above ground and 5% canopy cover. In addition, larger stems should predominate, specifically: 610 stems 10 to 25 cm dbh, 170 stems 25 to 50 cm dbh and 23 to 35 stems greater than 50 cm dbh per hectare should be provided. Clumping of these stems would allow for increased shrub development in the open areas and provide a more heterogeneous habitat able to support a higher diversity of species (*sensu* Roth 1976). This recommended habitat matches well with the known foraging habitat of these species during the breeding season in western Montana (Ramsden et al. 1979) and we also feel it would provide adequate nest sites. Water also appeared necessary for Fox Sparrows and MacGillivray's Warblers. These species were always found in close association with riparian thickets. Warbling Vireos and Swainson's Thrushes also preferred such areas. In accordance, we recommend stream-side and associated upland areas be given maximum protection from non-selective timber harvesting.

We cannot over emphasize the importance of percent cover and number of larger diameter stems to this community of birds, however, to the manager our precise recommendations may be difficult to implement. Therefore, we present values for more easily quantified snag variables which are associated with the preferred habitat of these bird species (Table 5). We must stress that snags, per se, do not make suitable habitat for these species but the structure of the living forest associated with the given number and basal area of snags does.

The preferred values for the snag measures are variable between species but two distinct groups are apparent. Townsend's Warblers, Warbling Vireos, and Golden-crowned Kinglets were associated with lower snag numbers and basal areas than were the other species. It is these three species that primarily depend upon upper strata foliage, hence exceedingly high snag numbers directly reduce their foraging and nesting substrate. Conversely, the other species are associated with very high snag values and depend primarily on shrub and low canopy foliage. This relationship is expected since more snags result in

a more open canopy and hence greater shrub development. Based on these conflicting requirements we propose two management alternatives. First, manage for intermediate snag numbers. A figure of 60 snags greater than 30 cm dbh per hectare or a snag basal area of approximately 2.0 m²/ha would be reasonable. Second, manage for high snag levels (80-90 snags >30 cm dbh, basal area of 4.0-5.0 m²/ha), but provide for a patchy snag distribution. This would allow good canopy development in some areas and good shrub development in others. We prefer this recommendation because overall avian diversity would be higher per stand and individual species density would not be lower than stands managed at intermediate snag levels.

The decision of which snag measure to use is also dependent upon bird species. Snag basal area is most indicative of upper strata cover and absence of small diameter stems. Therefore, it is most precisely related to the habitat requirements of Townsend's Warblers, Warbling Vireos, and Golden-crowned Kinglets in this study. The number of snags indicates presence of large diameter stems and shrub cover. Accordingly, the species depending upon these habitat variables (MacGillivray's and Wilson's warblers, Swainson's Thrush, Fox Sparrow) are more closely related to this snag measure. Number of snags greater than 30 cm dbh proved to be a better predictor of bird abundance, on the whole, than snag basal area and we therefore recommend its use, when dealing with a primarily shrub inhabiting community such as the one in this study.

These recommended snag densities are very high in comparison to studies concerned with habitat requirements of secondary cavity nesters (Evans and Conner 1979, Cunningham et al. 1980). However, the recommended stocking rate of lodgepole pine (*Pinus contorta*) in the northwest is 1500 stems per hectare, hence our highest snag density only requires 7% of the stems to be dead. Cavity nester studies also recommend that snags be in the 40 to 60 cm dbh size range, whereas, our recommendations are based on all snags greater than 30 cm dbh, which could inflate our recommendations. Although we did not monitor snag use by cavity nesters, we feel that these smaller snags may be used by bark gleaners and probers as foraging substrates (see also Brawn et al. 1982) and hence their inclusion in management recommendations is warranted.

Given that our study plots included several different coniferous species of managed and unmanaged stands, it is surprising that the relationships between cover, stem, and snag variables were so high. Since snag production depends on tree species (McComb and Muller 1983) a more precise estimate of required snag density could be gained by examining these relationships in each forest type separately. Utilizing such relationships to manage forests capable of perpetuating required snag levels will provide habitat suitable, not only for cavity nesters, but for sensitive open nesting species as well.

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Nest Boxes as a Coppery-Tailed Trogon Management Tool¹

Wendy A. Hakes²

Abstract.--Thirty nest boxes designed for Coppery-tailed Trogons (*Trogon elegans*) were observed in the Huachuca Mountains of southeastern Arizona from 1979-82. No trogons used them, but 7 vertebrates did. This study indicates nest boxes may not be an important management tool for trogons, but may be useful for other North American hole-nesters.

INTRODUCTION

The Coppery-tailed Trogon, a cavity-nesting bird, breeds in southeastern Arizona and Mexico. Approximately 100 trogons arrive in Arizona each April to occupy the pine-oak woodlands adjacent to the riparian habitats of the Chiricahua, Huachuca, Santa Rita, and Atascosa Mountains (Taylor 1980).

The human interest in Coppery-tailed Trogons is great--approximately 25,000 bird-watchers visit Arizona each year to see trogons and other birds unique to southeastern Arizona (Taylor 1980). The trogon population in Cave Creek Canyon of the Chiricahua Mountains is the most accessible and the most frequently visited by birders. Trogons, apparently, will not re-nest during a season if their eggs are destroyed.³ Concern about harassment of the birds and resulting nest failures prompted the U.S. Forest Service to prohibit the use of tape recorders to attract wildlife in Cave Creek Canyon since this disturbs breeding trogons.

Nest boxes have been used as a management tool for many North American vertebrates where there is believed to be a deficiency of natural cavities (Schemnitz 1980). Providing artificial nest structures resulted in an increase in breeding density of several species (Strange, et al. 1971; Hamerstrom, et al. 1973). This study was undertaken to determine if nest boxes could be

used as a management tool to increase the population of Coppery-tailed Trogons in Ramsey and Sunnyside Canyons in the Huachuca Mountains. A secondary objective was to gain additional information about the effects of competition, predation, and human disturbance on trogon nesting success.

I gratefully acknowledge the help given by the following people: J. Anderson for initiating this study; S. Crabtree, S. Peckham, and Boy Scout Troop 700 for building boxes; R. Taylor for his suggestions; the staff of the Ramsey Canyon Preserve, the Arizona Nature Conservancy, and United States Forest Service for their cooperation and assistance; bird-watchers and students for their field observations; J. Anderson, J. Dunning, J. Hardison, P. Krausman, S. Mills, and R. Taylor for identifying box contents; and D. Fuller, T. Huels, W. Mannan, and W. Shaw for editing suggestions.

METHODS

Thirty nest boxes were built to conform to the average dimensions of known trogon nests (table 1, fig. 1).³ Three-quarter inch pine and fir were used to provide adequate insulation (Kibler 1969). A traditional square and an octagonal design were used. The 8-sided shape made the boxes more tree-like in appearance. The outside surfaces were painted with a brown non-toxic paint to decrease the conspicuousness of the nest boxes. They were lined with an inch of dry grass and leaves and this lining was changed each season.

Twelve boxes were erected in Ramsey Canyon in 1979 at junctions of the main canyon with side canyons. Previous studies indicated that these locations are attractive nest sites for trogons.³ The remaining 18 boxes were erected in 1980 and had smaller entrance holes to limit access to predators (table 1). The 30 boxes were placed at heights ranging from 14-26 feet. Predator deterrents were put on 4 boxes after evidence of use

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²Wendy A. Hakes is a senior in Wildlife Ecology, University of Arizona, Tucson, Ariz.

³Taylor, R. C. 1978. Preliminary report: the distribution, population and breeding biology of the coppery-tailed trogon in Arizona. Unpublished report.

Table 1.--Dimensions of Coppery-tailed Trogon nest boxes.

Box	Dimension	Measurement
		-(inches)--
1-30	depth	16.0
1-30	interior	5.5-6.0
1-30	exterior	6.3-6.8
1-12	entrance hole	3.5
13-22	entrance hole	2.5
23-30	entrance hole	2.4

by Ringtails (*Bassariscus astutus*) increased (fig. 2). The boxes were checked every 2-3 weeks from early April to mid-August and the contents were examined after the young trogons in natural cavities had fledged. In 1982, questionnaires were given to bird-watchers at the Ramsey Canyon Preserve to supplement these observations. Birders were asked to provide information such as the activity, location, sex, and age of trogons in Ramsey and Sunnyside Canyons.

No Coppery-tailed Trogons nested in the boxes during the 4-year study, although 1 male did investigate a box in Ramsey Canyon.⁴ The populations in both canyons fluctuated slightly between years but did not increase. Ramsey Canyon had an average of 2 males and 1 female, and Sunnyside Canyon's population averaged 5 males and 3 females.⁵

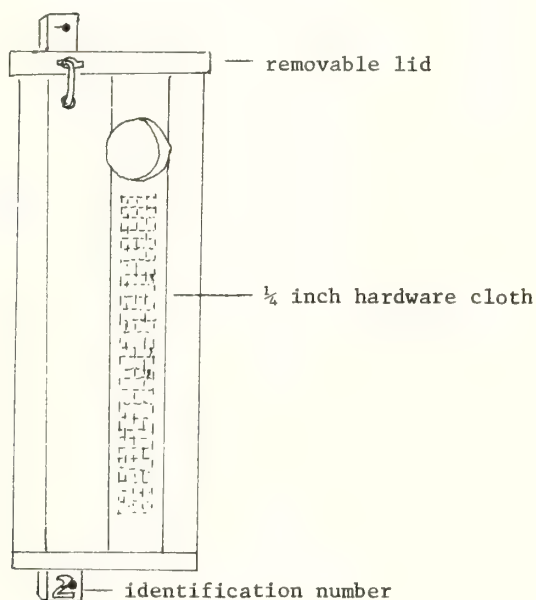


Figure 1.--Coppery-tailed trogon nest box.

⁴Rule, Virgil. 1982. Personal conversation. The Arizona Nature Conservancy, Tucson, Ariz.

⁵Taylor, R. C. 1982. The coppery-tailed trogon in Arizona, 1982. Unpublished report.

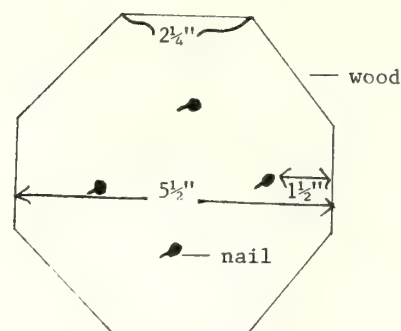


Figure 2.--Predator deterrent.

Use of Boxes by Other Animals

Although apparently not attractive to trogons, the boxes were used by several other birds: Flammulated Owls (*Otus flammeolus*), Whiskered Screech-Owls (*O. trichopsis*), Ash-throated Flycatchers (*Myiarchus cinerascens*), and Eastern Bluebirds (*Sialia sialis*) nested in the boxes (table 2). In 1982, Northern Flickers (*Colaptes auratus*) used 2 boxes as dump sites to lay extra eggs in.

The most frequent mammalian use of the nest boxes was roosting by Ringtails. Arizona Gray Squirrels (*Sciurus arizonensis*) also nested in at least 1 box.

DISCUSSION

Numerous variables could explain why Coppery-tailed Trogons did not use the nest boxes. These factors include statistical chance, population dynamics, entrance hole size, location within territories, competition, predation, human disturbance, nest tree status, physical attributes of location, height, and an abundance of natural nest sites.

The lack of use by trogons possibly is due to statistical chance. Compared with the number of natural nest cavities, the number of nest boxes is very small and the lack of use by the few nesting trogons simply may be due to chance. The population dynamics of Coppery-tailed Trogons in the United States may also be a contributing factor to the lack of use of the boxes. The Arizona population of trogons is small and is at the edge of its range. As such, this population may already be reproducing at its maximum potential. This idea appears to be supported by the presence of unmated males every year in all 4 mountain ranges.

The small entrance holes (2.4 and 2.5 inches) of 18 of the boxes may have discouraged use by trogons. These holes were at the low end of the range of hole sizes Taylor recorded for 38 natural nests. Only 2 nests have been recorded in the United States with holes under 3 inches in diameter.⁵

Table 2.--Use of Coppery-tailed Trogon nest boxes in Ramsey and Sunnyside Canyons, 1979-82.

Species	1979	1980	1981	1982	Total ¹
Coppery-tailed Trogon	0	0	0	0	0
Flammulated Owl ²	0	1	0	0	1
Whiskered Screech Owl ²	1	0	0	0	1
Northern Flicker	0	0	0	2	2
Ash-throated Flycatcher ²	0	0	1	1	1
Eastern Bluebird ²	0	0	1	0	1
Ringtail ³	0	3	5	4	8
Arizona Gray Squirrel ²	0	0	2	1	2
Invertebrates	6	10	14	13	23
Investigated/roosted	1	16	8	9	20
Total	8	24	23	25	28

¹Number of boxes used in 4 years.

²Boxes used for nesting.

³Boxes used for roosting.

In Sunnyside Canyon, most of the boxes were placed in areas occupied by trogons. Successfully breeding trogons keep other trogons out of their territories and often re-use previously used nest cavities. Consequently, other trogons may not have had a chance to investigate the nest boxes and the territorial pair continued using an old site. The logical solution would be place the boxes outside of trogon territories, but in Sunnyside Canyon, all suitable habitat appears to be occupied.

Competition between Coppery-tailed Trogons and other species for nesting cavities may have contributed to the lack of nest box use by trogons. Steele (1966) recorded a pair of trogons preempting a Northern Flicker pair from a cavity with 2 entrances. In 1982, I watched a male trogon drive a Sulphur-bellied Flycatcher (*Myiodynastes luteiventris*) from a cavity where the female trogon was incubating. Similar interactions between this cavity-nesting flycatcher and trogons have been observed in southeastern Arizona.³ A Whiskered Screech Owl was found roosting in a cavity previously used as a nest site by trogons and this species also roosted in the nest boxes. The other species that used the boxes also represent potential competitors for nest or roost sites, and, in some instances, the competitor may also be a predator. Heavy use of the nest boxes by Ringtails may present a threat to the trogons. However, I have no first-hand evidence of predation on Coppery-tailed Trogons.

Bent (1960), Steele (1966), and Taylor⁶ recorded nest failures due to human disturbances, such as nest photography, harassment, and shooting. Both Ramsey and Sunnyside Canyons are heavily used areas for multiple purposes. However, in this study, there was no evidence of human activities influencing trogon use of natural

cavities and, consequently, there is no reason to assume it affected their potential use of the nest boxes.

As secondary cavity-nesters, Coppery-tailed Trogons use existing cavities instead of excavating their own nests. Most natural nests are found in dead and dying trees⁵, because it is easier for woodpeckers, the original excavators, to drill in the softer wood (Kilham 1971; Conner, et al. 1976) that is a result of aging. I do not believe, however, that the placement of the nest boxes in live trees discouraged trogon use.

The physical attributes of the locations of the boxes does not seem to have been an important factor in the lack of use by trogons. All of the nest boxes were situated in habitat that was similar to that in which trogons nest and therefore presumably were suitable locations. The nest boxes were placed within the known range of heights for natural nests and consequently this should not have discouraged use.

A final point that should be stressed is the possibility that the availability of natural cavities is not a limiting factor in Arizona Coppery-tailed Trogon populations. The possibility also exists that the trogons find artificial nest cavities unsuitable for reasons we have not yet identified.

CONCLUSIONS

Coppery-tailed Trogons did not use any of 30 available nest boxes in 4 years. However, 5 bird species, 2 mammal species, and numerous invertebrates did use them. Nest boxes do not appear to have much potential as an important management tool for Coppery-tailed Trogons in the United States. Protection of trogon habitat no doubt is the most important management strategy (Pratt 1979).

⁶Taylor, R. C. 1981. The coppery-tailed trogon in Arizona, 1981. Unpublished report.

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Artificial Trees for Primary Cavity Users¹

Thomas C. Grubb, Jr.², Daniel R. Petit², and Dennis L. Krusac³

Abstract.--Downy woodpeckers (*Picoides pubescens*) excavated roosting cavities in artificial trees constructed of polystyrene "beadboard." In several studies completed and now in progress we have shown that this species of primary cavity user accepted artificial snags placed in mature deciduous woodland and in a 12-year-old clearcut area of a deciduous forest. Males of this species apparently preferred taller snags and excavated farther up on a snag of a given height than did females.

INTRODUCTION

Primary cavity users are animals such as woodpeckers which only roost and nest in cavities they themselves have excavated. This group will not use artificial boxes for roosting or nesting. By contrast, secondary cavity users routinely roost and nest in previously-existing cavities, often those abandoned by woodpeckers. Because this second group uses artificial nest cavities (i.e. nest boxes), they have been the subject of considerable basic and applied research (e.g. Franz 1961; Perrins 1979). Of particular interest to forest managers is the fact that populations of secondary cavity nesting birds can be increased by providing nestboxes to the point where they keep their woodland in leaf while neighboring tracts without nestboxes become defoliated by large numbers of insects (Bruns 1960).

The primary cavity nesting woodpeckers, heretofore beyond the reach of intense management practice, provide nesting sites for the secondary cavity users, but also directly exert important pressure on forest insects (MacCambridge and Knight 1972). Unfortunately, current silvicultural practices often dictate removal of dead and dying trees, precisely those required by woodpeckers. Here, we review recent work suggesting that artificial trees composed of polystyrene "beadboard" warrant consideration as a potential tool for basic and applied research on primary cavity users. We relate 1) a test of the attractiveness of artificial snags placed in a mature deciduous woodlot, 2) an

investigation of the height of artificial snags preferred by the downy woodpecker (*Picoides pubescens*) and 3) results of a project now in progress concerning artificial trees as a means of restocking woodpeckers into a 12-year-old clearcut.

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ARTIFICIAL TREES IN MATURE DECIDUOUS WOODLAND

From November 1979 through September 1980, we made 50 polystyrene cylinders available to the woodpeckers wintering and breeding in a 65-ha deciduous woodland in north-central Ohio. We first drilled a 3-cm diameter hole 80 cm longitudinally through the middle of each of the cylinders measuring 242 cm long and 22 cm in diameter. We then slid each cylinder down over a metal post driven into the ground in the experimental woodlot. Each cylinder was coated with brown latex paint in an effort to mimic tree color. The cylinders were spaced approximately 75 m apart in a grid pattern.

Results of this study are detailed elsewhere (Peterson and Grubb 1983) and will only be summarized here. Over the 11-month period during which we monitored the cylinders weekly, we found 51 cavities excavated in 42 of the 50 trees; nine trees exhibited two cavities each. The size and constancy of the cavity dimensions (table 1) indicate that of the seven woodpecker species known to breed and/or winter in Ohio, only the downy woodpecker used the cylinders. While downy woodpeckers were sighted near the cavities by day, and several were found roosting in cavities during night inspections, no other woodpecker species was so associated with the artificial snags. Perhaps, this result was to be expected as only the downy wood-

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²Thomas C. Grubb, Jr. and Daniel R. Petit are, respectively, Professor and Graduate Research Associate of Zoology, The Ohio State University, Columbus, Ohio 43210.

³Dennis L. Krusac is Wildlife Biologist, USDA Forest Service, 1 Pinchot Place, Athens, Ohio 45701.

Table 1.--Dimensions of 51 cavities excavated in artificial trees by downy woodpeckers.

Parameter	Mean	SD
Cavity depth ¹ , cm	17.1	4.2
Distance from cylinder top to entrance hole ¹ , cm	38.1	24.6
Entrance area ² , cm ²	17.0	5.2
Diameter of cavity ³ , cm	10.1	1.0

¹Measured from the lower lip of the entrance hole.

²Entrance area = $\pi(\frac{1}{2} \text{ entrance height}) \times (\frac{1}{2} \text{ entrance width})$.

³Measured from the inner edge of the lower lip of the entrance hole.

pecker, among the seven Ohio species, is known to accept natural snags as small as our cylinders (Thomas et al. 1979).

We found indications that downy woodpeckers made seasonal adjustments in the character of their cavities. Entrances to cavities dug in summer (April-September) were randomly oriented; those entrances of cavities fashioned in winter (November-March) were non-randomly oriented with a statistically significant mean vector of 72°. As the cylinders were all of homogeneous composition and were all positioned vertically, such potentially causal factors as tree lean and heterogeneous composition can be discounted. We conclude that, in winter, the woodpeckers excavated their cavities to face away from the prevailing southwesterly winds.

The second property of cavities that varied with time of year was their depth. Cavities excavated in winter were significantly deeper than those dug in summer. Over winter and summer taken together there was a significant negative correlation between temperature (°C) and cavity depth (cm; $y = -0.31x + 20.8$; $r = -0.75$; $P < 0.01$).

Although no woodpeckers bred in the artificial-tree cavities, we tallied 30 nests of secondary cavity nesters in the cylinders, two nests of the Carolina chickadee (*Parus atricapillus*) and 28 nests of the house wren (*Troglodytes aedon*).

From this initial project with artificial trees we concluded that one primary cavity using species, the downy woodpecker, readily accepted polystyrene as a roost-hole substrate, and apparently even preferred this substance to the natural snags from which they moved to the cylinders. Downy woodpeckers are the smallest woodpecker in Ohio, and we hypothesized that other species might require larger cylinders.

PREFERRED SNAG HEIGHT IN THE DOWNY WOODPECKER

Having established that downy woodpeckers, at least, would accept artificial trees as surrogate snags, we felt it important for future studies of a manipulative nature to ascertain the preferred height of snags to be used as excavation sites by

individuals of this species. The sexes of this species have different foraging techniques, possibly to reduce intersexual competition for food resources (Williams 1975), so the question arose as to whether males and females might reduce competition by excavating on different sized snags, or at different heights on the same size snag. Accordingly we conducted an experiment in which downy woodpeckers were given a choice among different sized snags as an excavation site.

Grubb (1982) presents a detailed report of procedures and results. Briefly, 16 trios of snags were set out in Ohio woodlots during October-December 1980. Each trio consisted of cylinders 121, 242 and 363 cm in length placed randomly in the formation of an equilateral triangle with sides of 3 m. We checked each trio daily until we found a cavity, defined as any excavation deeper than 10 cm, and noted the sex of the downy woodpecker flushed from or seen in the vicinity of the cavity.

Of 16 birds monitored, 10 dug cavities in the intermediate (242-cm) cylinders, a significant departure from random choice. The small sample size prevented statistical confirmation of the apparent choice by females of snags shorter than those chosen by males. Nevertheless, while one female and no males chose 121-cm snags, five males and no females dug in the tallest (363 cm) snags. Furthermore, in the cases where males and females both dug in the same, intermediate, sized snags, males excavated significantly closer ($\bar{x} = 31 \pm 4$ cm, $N = 6$) to the top of a cylinder than did females ($\bar{x} = 131 \pm 19$ cm, $N = 4$).

We concluded from this snag-choice experiment that downy woodpeckers, as a species, apparently preferred about 2.5-m-high cylinders in which to fashion cavities, and that artificial trees of this height might be most effective in subsequent investigations. We also concluded that our sample, while a small one, suggested that the sexes of this woodpecker species in Ohio might be reducing competition for cavity sites in ways previously unsuspected. With our initial studies demonstrating an acceptance of about 2.5-m cylinders as cavity sites by *P. pubescens*, we felt prepared to attack the question of whether surrogate snags could be used to accelerate recolonization of this species into recently clearcut areas of deciduous forest.

ARTIFICIAL TREES IN A CLEARCUT

During 1982-83, we investigated the important question of whether artificial trees can accelerate recolonization of clearcut habitat by primary cavity users. We emphasize at the outset that this project is currently in progress (Petit and Grubb, in preparation), so results presented here will be preliminary in nature.

In September 1982, we located two 12-year-old clearcut tracts of deciduous trees in Wayne National Forest, Ohio. Both plots were approximately 10 ha in area with a southerly exposure and slope of 20-30°. In one of these two matched clearcuts, we erected 99 artificial trees in a 9 x 11 grid

matrix with 16 m between adjacent trees in the same grid line. We had previously determined that downy woodpeckers readily accept surrogate snags square rather than round in cross section. Because square "trees" are cheaper to fabricate and easier to handle, we used 20- x 20- x 242-cm artificial trees in this study of clearcuts.

During the study to date, we have been monitoring cavity construction in the area with the surrogate snags, censusing woodpecker populations in the control and experimental plots at biweekly intervals, and recording woodpecker-caused mortality of the larvae of red oak borers (*Enaphalodes rufulus*) in the two plots. The red oak borer is an important pest in eastern deciduous forests. We planned to determine whether any increased presence of woodpeckers, correlated with the addition of artificial snags, might also be correlated with increased mortality of this insect. At the time of this writing, nesting behavior of primary and secondary cavity users is just commencing. During the coming summer months, we will monitor reproductive activity in the artificial trees.

As of April 1983, woodpeckers excavated cavities in 17 of the 99 artificial trees in the experimental clearcut. As before, the dimensions of the cavities indicate that all have been made by downy woodpeckers. Our experimental plot is bordered by mature forest on two sides. The pattern of artificial trees with cavities (fig. 1) suggests that the downy woodpeckers colonized the clearcut

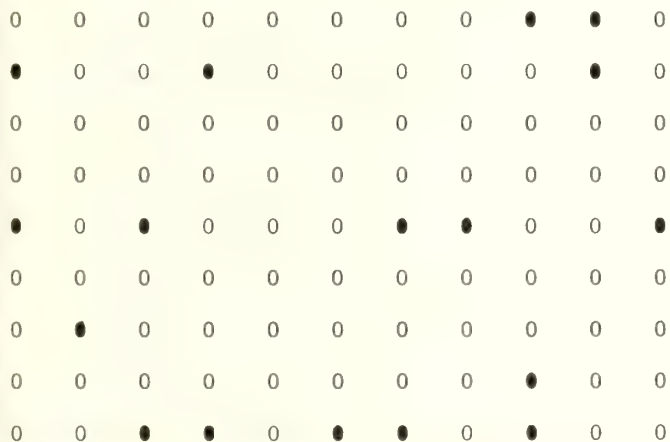


Figure 1.--The grid matrix in which 99 artificial trees were arranged within a 12-year-old clearcut in September 1982. The distance between adjacent trees in each row was 16 m. By April 1983, downy woodpeckers had excavated cavities in surrogate snags marked by blackened circles.

gradually from the surrounding woodland. Only 3 of the 35 central cavities (9%) contained cavities. During the course of the winter, a maximum of 6 downy woodpeckers were tallied in the experimental plot and a maximum of 3 birds of this species occurred in the control plot. As censusing is still being conducted, we do not yet have a final statis-

tical determination of whether downy woodpeckers were more dense in the clearcut.

Red oak borers were found in September 1982 by locating their exit holes in red oak saplings. By April 1983, 11 of the 148 borers (7.4%) had been preyed upon by woodpeckers in the experimental area and 11 or 86 (12.8%) had been eaten by woodpeckers in the control plot. Thus, it appears that the increase in downy woodpecker numbers in the experimental site had no effect on the mortality of this boring insect. Red oak borers have a two-year life cycle. By their second winter, they have bored so deeply into the stems of trees that they are probably invulnerable to attack by downy woodpeckers. Red oak borers in Ohio have synchronized life histories so that almost all adults emerge in odd-numbered years (Donley and Acciavatti 1980). Thus, almost all the borers we monitored during the 1982-83 winter were at the deeply-imbedded stage inaccessible to downy woodpeckers. Periodically, we encountered the larger hairy woodpecker (*Picoides villosus*) on both plots. Birds of this species may have been responsible for the borer mortality we did record.

Although a detailed analysis awaits the conclusion of our field work, we tentatively conclude that downy woodpeckers will colonize a recently clearcut area if they are provided with artificial substrate for digging their cavities. We also conclude that such increased presence of this woodpecker species has no impact on the level of red oak borers during the insects' second winter. The question remains open whether downy woodpeckers attracted to a clearcut by artificial snags might cause significant mortality to red oak borers during the insects' first winter when each larva is smaller and is lying dormant just beneath the bark surface, well within the range of foraging downy woodpeckers.

DIRECTIONS OF FUTURE RESEARCH

Artificial trees may offer the opportunity for basic research on the life histories of woodpeckers. Specifically, questions such as those concerning resource limitation, territoriality and habitat selection appear open to manipulative testing with surrogate snags. However, before this tool can have wide application, two obstacles must be overcome. First, we must discover why no downy woodpeckers have yet nested in the cavities they have constructed in artificial trees. On the premise that adequate surfaces for the birds' drumming behavior have been previously lacking, we are currently evaluating the effect of plywood resonating boards affixed to the polystyrene blanks now in Wayne National Forest.

The second obstacle to progress concerns why only the downy woodpecker has used artificial trees. Based on the hypothesis that the other, larger species require taller and/or larger blanks, we are collaborating with James Parker of the Naval Ordnance Station, Indian Head, Maryland in evaluating polystyrene blanks up to twice as tall and four times as great in cross-sectional area as those we have used previously.

From the perspective of applied research, it has yet to be established firmly that artificial trees can facilitate recolonization by primary cavity users of such disturbed habitats as forest clearcuts and reclaimed stripmined land. Whether surrogate snags might increase the impact of woodpecker predation on insect pests in forests also remains an open question.

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Use of Nesting Boxes on Young Loblolly Pine Plantations¹

George A. Hurst²

Abstract.--Use of nesting boxes, 17-45 per area from 1977-83, on 2 loblolly pine (*Pinus taeda*) plantations in Mississippi was monitored from plantation age 1-7 years. Most of the use (nest attempts) was made by the eastern bluebird (*Sialia sialis*) with total use by the bluebird and the Carolina chickadee (*Parus carolinensis*) being 32%, 139 nest attempts, over the 7-year period. Bluebird use of and production in the boxes was highest at plantation age 3 and was lowest at age 7. Chickadee use began with 1 nest attempt on each plantation at age 3 (1979) and use remained low, 2 or 3 attempts/year, on 1 plantation. Attempts on the other plantation numbered 4 (1980) and 3 (1981) but increased to 10 (1982) and 8 (1983).

INTRODUCTION

Southern forests are expected to produce more wood products with the increase in pine (*Pinus* spp.) production occurring on intensively managed pine plantations. Often, mature pine-hardwood forests are converted to pine plantations. Some 20.25 million ha of pine-hardwood forests might be converted to plantations (Walstad 1976). There are about 11.7 million ha of pine plantations in the South, and over 0.41 million ha are being established annually (Mann 1975, Montgomery 1983³).

After a pine-hardwood forest is clearcut the area is site prepared by chemical or mechanical methods. Chemical methods can create many snags, but mechanical methods such as tree-crush, roller-chop, or shear-rake-disk-bed destroy most existing and potential snags.

Some secondary cavity nesters will use nesting boxes, and boxes have been tried in some forest types in the South (McComb and Nobel 1981). Nesting boxes have been placed in forests in England and Europe (Franz 1961, Cambell 1968). This study

was conducted to determine use of nesting boxes on pine plantations age 1-7 years.

STUDY AREAS

Two loblolly pine plantations near Longview (Oktibbeha County), Mississippi, in the Interior Flatwoods Land Resource Area of the Upper Coastal Plain were used (Pettry 1977). Each plantation was 65 ha in size and was located about 1.6 km apart (Hurst 1980a).

Both areas had been about 50-year-old pine-hardwood forests dominated by pine, oak (*Quercus* spp.), and hickories (*Carya* spp.). The forests were clearcut in the summer and site prepared in the fall of 1976. Site preparation consisted of shearing, windrowing, and bedding. Pine seedlings were hand-planted on a 2.1 x 2.4 m spacing or 1,922 trees/ha in March 1977.

Annual and perennial forbs, grasses, sedges, and vines were the dominant plants for 2 years with pine trees, hardwood brush, and blackberry (*Rubus argutus*) dominating the plantations thereafter (Darden 1980). Pine trees averaged 1.8 m tall after the third growing season. At the end of the sixth growing season average pine stand conditions were dbh 8.79 cm, height 5.3 m, basal area 12.6 m²/ha and stocking 1,634 trees/ha.

Both plantations were surrounded by mature pine-hardwood forests until 1978. From 1978 to 1982 a total of 583 ha of pine-hardwood forests

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²George A. Hurst, Professor, Department of Wildlife and Fisheries, Mississippi State University, Mississippi State, MS.

³Montgomery, J.M. 1983. Personal conversation. Southern Forest Institute, Atlanta, GA.

near the study areas was converted to pine plantations. Some small hayfields and pastures were in the vicinity of the study areas.

METHODS

In March 1977, 40 wooden nesting boxes with 4 different dimensions, e.g. 10.2 x 10.2 x 20.3 cm and 12.7 x 12.7 x 20.3 cm, were placed on each plantation (Hurst et al. 1979). In addition 5 plastic milk jugs (4.55 l), which were painted white and had 3.8 cm entrance holes, were erected on each plantation (Stewart 1976). Jugs were on the plantations only in 1977 and 1978. The wooden boxes had entrance hole diameters of 3.2, 3.8, and 5.1 cm. The number of boxes on the plantations changed over the study period (Table 1). Three boxes, 15.2 x 15.2 x 38.1 cm, with 5.1 cm entrance holes, were placed on large trees on 1 pine-hardwood/plantation edge. These boxes were removed after the 1978 nesting season.

The boxes were attached to creosoted posts with a diameter of 7.6 cm and the posts were driven into the ground so that the entrance holes were about 1.37 m above ground. In 1983 some boxes were wired to pine trees and other boxes were attached to 3.81 cm diameter polyvinyl chloride pipe, which was placed over a steel rod. Both the rod and pipe were pushed into the ground and a box was clamped to the pipe.

In 1977 and 1978 the boxes were placed in 5 rows, which were about 55 m apart. The first row was about 20 m from a pine-hardwood forest. This row was removed after the 1978 nesting season. Boxes within a row were about 55 m apart. In 1979 the distance between rows and between boxes within rows was increased to about 91.4 m, and the number of rows was increased to 6 on one area and 7 on the other area. The number of rows was changed to 5 on both areas in 1981. The boxes were on an area of about 16.2 ha in 1977 and 1978, and about 34 ha in 1979-83.

Box use was monitored at 7-10 day intervals from March through August. Boxes were cleaned in February. Some vegetation was cut to improve walking conditions between boxes and to make the boxes more visible.

Creosote was poured on the lower part of posts that had active nests in 1977 and 1978. Conical metal guards were placed on some posts with active nests from 1979-83. A 5 cm wide band of Stikem^R (Polymerized 1-Butene) was placed on all posts with active nests in 1979-83.

RESULTS

Bluebirds and Carolina chickadees used a total of 114 (26%) of a possible 436 boxes over the 7-year period, based on single use of a box. Multiple use of a box by 1 or both species was 32%, 139 uses of 436 boxes.

Bluebirds used plastic jugs and wooden boxes with 3.8 and 5.1 cm holes, but they would not use boxes with 3.2 cm holes (Zeleny 1976); therefore bluebird use of acceptable boxes was 84 (30%) of 280 boxes. Multiple use of boxes by bluebirds was 102 (36%) of 280.

Bluebird production, based on number of nest attempts, number of eggs laid and hatched, and number of fledglings produced, peaked at plantation age 3 and was lowest at age 7 (Table 2). Of the 102 bluebird nest attempts 82% were successful, i.e. produced at least 1 fledgling. A total of 427 bluebird eggs was laid, of which 351 (82%) hatched and 328 (93%) of the nestlings fledged. Average clutch size was 4.5 (3-6).

Chickadees began using boxes at plantation age 3, with 1 nest attempt on each area. The number of nest attempts on plantation number 1 was 2 (1980, 1981, 1983) and 3 (1982). Plantation number 2 had 4 nest attempts in 1980, 3 (1981), 10 (1982) and 8 (1983). Twenty seven (75%) of the 36 chickadee nest attempts were successful. A total of 190 chickadee eggs was laid of which 134 (70%) hatched and 118 (88%) of the nestlings fledged. Average clutch size was 5.4 (2-7).

Chickadees used boxes with 3.2 and 3.8 cm holes and used boxes on posts, on pvc pipe, and boxes wired to trees. Chickadees began nesting in mid-March and fledging was over by late May. Bluebird nesting began in late March to early April with most fledging completed by late July. Bluebirds built their nests on active chickadee nests on 4 occasions.

Carolina wrens (*Thryothorus ludovicianus*) made 2 nest attempts in boxes on the plantation/forest edge. Wrens did not use boxes in the plantations.

Losses of eggs and nestlings were attributed to the imported red fire ant (*Solenopsis vicia*) and the little black ant (*Monomorium minimum*) (Hurst 1980b). Other losses were caused by a raccoon (*Procyon lotor*) and a snake. Nest abandonment occurred sporadically but was a major cause of unsuccessful bluebird nests on plantation number 2 in 1980.

DISCUSSION

Use of boxes on the plantations was limited to the bluebird and the chickadee. Bluebird use of boxes was 30% (single use) and 36% (multiple use) over the 7-year period, which was less than the 49% use reported for bluebird trails in 1982 (Dupree 1983). Bluebird use of the boxes was highest at plantation age 3 with major declines in use at age 6 and 7. Heard (1979) found much greater bluebird use of boxes on new clearcuts than on older plantations, age 4-8, in North Carolina. Mature pine-hardwood forests are not preferred bluebird breeding habitat so the cre-

Table 1.--Use of nesting boxes by bluebirds and Carolina chickadees in two loblolly pine plantations, Longview, Mississippi.

Year	Plantation		No. boxes by entrance hole diameter (cm)			No. boxes used ¹	No. times a single box was used			Use (%) of all boxes ²	Use (%) by bluebirds ³
	Age(Yr)	No.	3.2	3.8	5.1		1	2	3		
1977	1	1	19	21	5	9	9	0	0	20	35
		2	29	14	2	5	3	2	0	11	31
1978	2	1	19	21	5	4	3	1	0	9	15
		2	22	21	1	4	0	3	1	9	18
1979	3	1	11	22	5	11	10	0	1	29	37
		2	11	19	1	12	5	5	1	39	60
1980	4	1	8	22	0	10	9	1	0	33	41
		2	3	18	0	9	8	1	0	43	33
1981	5	1	8	14	0	7	5	2	0	32	36
		2	1	20	0	11	9	2	0	52	45
1982	6	1	2	16	0	5	5	0	0	28	12
		2	1	16	0	15	13	2	0	88	38
1983 ⁴	7	1	10	17	0	3	3	0	0	11	6
		2	12	20	0	9	9	0	0	28	5

¹Use was considered to be a complete nest in which at least 1 egg was laid.

²Percent use was figured on first use only, does not include multiple use of the same box.

³Bluebird use was figured for boxes with 3.8 or 5.1 cm entrance holes.

⁴Use was monitored only through June 1.

Table 2.--Bluebird production in nesting boxes in two loblolly pine plantations, age 1-7 years, Longview, Mississippi.

	Nest Attempts ¹				Eggs				Number Fledged	
	Suc.		Unsuc.		Laid		Hatched			
	1	2	1	2	1	2	1	2	1	2
1977	6	7	3	0	33	29	22	28	22	28
1978	5	9	0	0	23	38	23	36	23	36
1979	7	15	5	2	45	72	34	61	27	57
1980	9	2	0	4	41	22	33	8	31	8
1981	7	8	0	2	33	45	29	38	25	34
1982	2	5	0	2	10	27	9	22	9	20
1983 ²	1	1	0	0	4	5	4	4	4	4
Total	37	47	8	10	189	238	154	197	141	187

¹An attempt was considered to be a complete nest in which at least 1 egg was laid. Suc=successful means at least 1 bluebird fledged. Unsuc=unsuccessful means no fledglings were produced.

²Use was monitored only through June 1.

ation of clearcuts and the addition of artificial nesting cavities benefitted this species.

Chickadees were said to be most common in mixed pine-hardwood forests, and the breeding habitat was mature woods (Hamel et al. 1982). Dickson et al. (1980) and Johnson and Landers (1982) found that chickadees had low relative abundances in loblolly-shortleaf (*P. echinata*) and slash pine (*P. elliottii*) plantations in the South. McComb and Nobel (1981) found little use of nesting boxes by chickadees in 3 mature forest types, including a pine-hardwood forest in Mississippi. Chickadee use of boxes on the pine plantations began at age 3 and remained low on 1 plantation, but increased considerably on the other plantation, 10 nest attempts, at age 6. Perhaps Carolina chickadee populations can be increased by nest box programs in loblolly pine plantations (Dahlsten and Copper 1979) and provide some insect control (Evans and Conner 1979).

The reason other secondary cavity nesters did not use the boxes on the plantations might be explained as follows. First, most of this part of Mississippi is still in mature, mixed-type forests, which have no apparent lack of snags/cavities. Also, there are active nesting box programs in the area. Lack of suitable nesting boxes was another reason for limited use of plantations. The great crested flycatcher (*Myiarchus crinitus*) used nesting boxes on loblolly pine plantations age 5-7 in Louisiana⁴. Suitable flycatcher boxes were on these study areas only at plantation age 1 and 2. Vegetative conditions were unacceptable to the tufted titmouse (*Parus bicolor*), a species that prefers deciduous woods to pine (Hamel et al. 1982). Carolina wrens used boxes placed on the mature pine-hardwood forest/plantation edge but not boxes in the dense vegetation on the plantation. Perhaps the lack of a woodland canopy was the limiting factor (Hamel et al. 1982).

Vegetative conditions changed rapidly in the pine plantations affecting the plant community surrounding the boxes. Use of nesting boxes should be determined throughout a short, 25-35 years, rotation and following various intermediate silvicultural treatments, such as pre-commercial thinning and controlled burning.

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⁴Robert Hamilton, School of Forestry and Wildlife Management, Louisiana State Univ., Baton Rouge, LA.

Use of Nest Boxes in Ponderosa Pine Forests¹

Jeffrey D. Brawn² and Russell P. Balda³

Abstract. Use of nest boxes by secondary cavity nesting birds was assessed on 3 study plots in northern Arizona's ponderosa pine forests from 1980 to 1982. Sixty boxes were installed on each of the 8.0 ha plots. Box use as nest sites increased, overall, from 5% to 31% during the 3 breeding seasons. Differences in % use between plots were related to the availability of natural nest sites in snags. To date, 6 species have nested in the boxes. Nest attempts were 73% successful. The employment of nest boxes as a management tool may become more viable if current trends in land use practices persist.

INTRODUCTION

All organisms have certain requirements that must be satisfied in order to survive and reproduce. The habitat requirements of non-game birds have received considerable attention with much recent work focusing on the interaction between timber management and avian habitat needs (e.g. USDA For. Serv. 1980).

An especially large amount of research has been devoted to cavity nesting birds and their relationships with snags, i.e. dead or dying trees. Such research is abundant because: (1) cavity nesters are a diverse group of birds; (2) many aspects of cavity nester habitat needs are relatively specific and easily quantified; and (3) the reliance of cavity nesters on snags renders them vulnerable to certain land use practices. Investigations of many aspects of cavity nesting bird biology have been performed including; types of snags used for nesting (Connor and Adkisson 1977, Scott 1978, Cunningham et al. 1980); densities of snags suitable for support of viable populations (Balda 1975, Scott 1979); and use of snags as foraging substrates (Brawn et al. 1982). These studies have clearly demonstrated, by either experimental or descriptive analyses, the critical importance of snags to cavity nesters. Moreover, virtually all research has supported the notion that strict silvicultural management of forests is selective against snags, and that density of snags and/or nest holes is a good predictor of cavity nester densities.

The objective of alleviating the negative impact of certain silvicultural practices on cavity nesters has generated several management options. These options include: (1) retention of a certain density of suitable (i.e. large enough) snags on a managed stand (Balda 1975, Scott 1978); (2) letting a certain amount of a stand mature to or remain in old growth conditions (Hardin and Evans 1977); (3) creation of snags by either routing out holes (Carey and Sanderson 1981), killing trees (Bull et al. 1980), or fungal inoculation; and (4) installation of nest boxes.

The first two of the above options are likely the best in terms of a holistic approach to the maintenance of cavity nester populations; however, certain factors are becoming increasingly serious which may, unfortunately, mitigate their use in the future. Projected demands for wood fiber and resources (i.e. land) available to meet these demands are likely to result in an increasingly intense level of silvicultural management on many forests (Gould 1980). In addition, and perhaps as important, the ever increasing public demand for fuelwood is having a dramatic impact on the "life expectancy" and density of snags (Scott et al. 1980).

Interestingly, most research on cavity nesters has dealt with primary cavity nesters (PCNs); i.e. species which are able to excavate their own nest and roost holes. A tacit assumption of such studies has been that if PCNs are provided for, then the species which are unable to excavate, or secondary cavity nesters (SCNs), will also be accommodated. Whereas this assumption is intuitively sound, it has resulted in a general avoidance of research on the last of the aforementioned management options for cavity nesters, i.e. nest boxes.

Nest boxes have been widely used in Europe for much of the 20th century (Bruns 1960, von Haartman 1971). Boxes have generally maintained populations of SCNs in habitat which would otherwise be unsuitable. In certain instances the results have been dramatic, and many-fold increases in SCN breeding densities have

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²Jeffrey D. Brawn is a Research Assistant at the Department of Biological Sciences, Northern Arizona University, Flagstaff, Ariz.

³Russell P. Balda is a Professor of Biology, Department of Biological Sciences, Northern Arizona University, Flagstaff, Ariz.

been recorded (von Haartman 1956, 1971). Commercial forests in much of Europe are intensively managed and it is likely that the presence of boxes has prevented local extirpations of many SCNs.

In North America, nest boxes have been employed on a relatively small scale. Generally, their use has been limited to game species or selected non-game species such as Eastern Bluebirds (*Sialia sialis*) (Pinkowski 1977). Certain workers have, oddly, resisted the idea of nest boxes as a management option in North America (Miller and Miller 1980). A typical objection to boxes is that they furnish only one of the resources which snags offer, i.e. unused holes for SCNs. This consideration is valid but does not diminish the utility of boxes as part of the solution to effective cavity nester management.

If boxes are to be used as an effective management tool in North America it will be necessary to have baseline data concerning their use. Prior to the present study, no large-scale nest box programs for non-game birds have been conducted in western coniferous forests (Smith 1980). This paper will report on some of the results of a study designed to assess the efficacy of nest boxes in ponderosa pine forests. The objectives of this study were:

- (1) to determine if SCNs will utilize nest boxes in ponderosa pine forests;
- (2) to monitor the success of SCNs that breed in boxes; and
- (3) to determine the cost of a nest box program.

Other aspects of this study such as effects of boxes on SCN populations, SCN habitat selection, and management recommendations will be reported on elsewhere.

METHODS AND MATERIALS

Field work was conducted on 3 study plots, all located within the USFS Beaver Creek Watershed Project located south of Flagstaff in the Coconino National Forest, Coconino County, Arizona. Each plot covered 8-8.5 ha.

All plots consisted of ponderosa pine (*Pinus ponderosa*) dominated stands with varying densities of gambel oak (*Quercus gambeli*). Elevation of the plots varied from 2100 to 2300 m. Average annual precipitation and temperature on the Beaver Creek Watershed are approximately 64 cm and 7.2°, respectively.

The three plots differed in silvicultural histories: one plot (WS-13) was uncut for approximately 60 years; one plot (WS-8) was moderately thinned in 1974; and one plot (WS-17) was severely thinned in 1969. Silvicultural profiles of the plots are shown in table 1. Importantly, snag densities on the WS-13, WS-8, and WS-17 plots were high, medium, and low, respectively.

Type and Installation of Boxes

Boxes used in this study were made from a mixture of concrete and wood chips and were purchased in W. Germany. The boxes were cylindrical with the following dimensions:

- Total Height - 25 cm
- Distance from Hole to Bottom - 17 cm
- Outside Radius - 10 cm

Inside Height - 21 cm

The volume of each box was approximately 1900 cm³. Boxes were installed by hanging them on metal-wood holders which had been nailed to tree trunks.

Sixty boxes were installed on each plot; thus, a total of 180 boxes were used for this study at a density of about 7 boxes/ha. Boxes were installed during the spring of 1980.

Four types of boxes were installed on each plot; large-hole (38 mm) and small-hole (32 mm) with and without sawdust. Hole size is important because SCNs usually prefer to use nests with holes just large enough for them to pass through. The hole sizes we selected accommodate all potential avian inhabitants of the boxes in northern Arizona (raptors were not within the scope of this study). Sawdust was provided for those species which are known to partially excavate nest holes in snags and/or modify old woodpecker holes.

Boxes were spaced evenly throughout the plots using grid-markers as guides. The distribution of boxes on WS-17 was, necessarily, somewhat uneven due to the limited availability of trees suitable for hanging boxes.

Assessment of Box Use and Breeding Success

Each box was checked at least twice during each breeding period from 1980 to 1982. Boxes found to be in use were checked more frequently.

Nesting success of box occupants was closely monitored. All boxes used during the breeding period were cleaned out during the following fall.

RESULTS AND DISCUSSION

Use of Boxes--Overall Response

The number of boxes used for nesting increased over six-fold between 1980 and 1982 (table 2). The greatest response to the boxes occurred on WS-8 where an average 22% contained active nests each year. The smallest response occurred on WS-13 which had only an average 7% nesting use. The use of boxes on all three plots, however, has increased each successive year. Within each plot the largest increases were between the 1980 and 1981 breeding seasons.

The build-up of box use on all plots resulted from two trends: (1) within a given species more pairs nested in boxes each year; and (2) more species used the boxes each year. For example, on WS-8 in 1980, 2 Western Bluebird (*Sialia mexicana*) and 2 Pygmy Nuthatch (*Sitta pygmaea*) nests were found, whereas in 1982 we found 9 Western Bluebird, 5 Pygmy Nuthatch, 9 Violet-green Swallow (*Tachycineta thalassina*), 1 Mountain Chickadee (*Parus gambeli*), and 1 White-breasted Nuthatch (*Sitta carolinensis*) nests.

Use of Boxes by Species

To date, 6 species have nested in the boxes (table 3). Mountain Bluebirds (*Sialia currucoides*),

Table 1. Silvicultural Profiles of Study Plots

Plot	Tree Species	Criterion					
		Relative Density	Relative Dominance	Relative Frequency	Importance Value	Absolute Density (trees/ha)	Number of Snags
WS-17	<i>P. ponderosa</i>	81	87	69	237	57	7
	<i>Q. gambeli</i>	19	13	31	63	12	
WS-17C	<i>P. ponderosa</i>	68	65	62	198	52	9
	<i>Q. gambeli</i>	32	35	38	102	21	
WS-8	<i>P. ponderosa</i>	92	94	82	268	209	21
	<i>Q. gambeli</i>	8	6	18	32	16	
WS-8C	<i>P. ponderosa</i>	89	91	79	259	217	18
	<i>Q. gambeli</i>	11	9	21	41	19	
WS-13	<i>P. ponderosa</i>	90	86	77	253	583	39
	<i>Q. gambeli</i>	8	8	19	36	54	
	<i>J. deppeana</i>	2	6	4	11	9	

Purple Martins (*Progne subis*), and Red-breasted Nuthatches (*Sitta canadensis*) are the only local SCNs which have yet to use the boxes. Considerable inter-specific variation with regard to box use has been found. Western Bluebirds have utilized the boxes most readily on all three plots. Violet-green Swallows began to use the boxes in low numbers during 1981 on WS-8 and WS-13. In 1982 swallows nested in the boxes on WS-8 and WS-17 in relatively high densities. Bluebirds and swallows are both migratory species. Among permanent residents, box usage has been greatest with Pygmy Nuthatches, followed by Mountain Chickadees and least with White breasted Nuthatches and House Wrens (*Troglodytes aedon*). Based on preliminary data from 1983, however, White-breasted Nuthatch use of the boxes is increasing.

The relatively meager overall response on all three treatment plots in 1980 has several potential explanations. On WS-8 and, especially, WS-13, the boxes were installed rather late in relation to timing of SCN breeding due to snow conditions. In addition, the winter previous to the 1980 breeding period was, even by local standards, quite severe. Another, ongoing study on avian communities in northern Arizona

has found that adverse winter conditions can have a distinct negative effect on bird populations (Balda et al. this volume). Finally, a period of "adjustment" may be required before all the SCNs recognize the boxes as potential nest sites. A type of social facilitation is possibly involved; that is, birds observe use of boxes by other birds and subsequently learn that the boxes are an exploitable resource. Studies concerning box use by Wood Ducks (*Aix sponsa*) have also noted a gradual increase through time in the proportion of boxes used (Doty and Kuse 1972).

The overall disparate response to the boxes on the plots is likely due, in part, to the availability of natural nest sites. The number of boxes divided by the number of excavated holes counted on snags within the plots were: WS-13, 1.2; WS-8, 1.9; and WS-17, 8.57. A correlation between these ratios and the % of SCN nests found in boxes indicated a significant positive relationship ($r = .67$, $df = 7$, $P < 0.05$). This indicates that availability of snags and box usage are mutually dependant. If box usage continues to increase on WS-13 as it did between 1981 and 1982, however, this relationship will become less distinct. These data indicate that availability of snags may precipitate a lag in box usage but that boxes will eventually be utilized. Further research will be required to properly evaluate this matter. The question of why certain species respond to boxes more than others will be considered elsewhere (Brawn and Balda, in prep.).

Table 2. Number of boxes with nests on treatment plots from 1980 to 1982.

Plot	Number of Boxes Used (%)*		
	1980	1981	1982
WS-17	3 (5)	13 (22)	24 (40)
WS-8	6 (10)	22 (37)	24 (40)
WS-13	0	4 (7)	8 (13)
Overall Usage	9 (5)	39 (22)	56 (31)

*Boxes with two nests in one season are counted once.

Nesting Success of Birds Using Boxes

Overall, 73% of the nesting attempts in boxes were successful; that is, at least one nestling fledged (table 4). This success rate agrees favorably with what has been found for cavity nesters and/or temperate passerines (Nice 1957, Ricklefs 1969). Thus, it does not appear that the boxes used in this study present any particular liability to breeding birds.

Table 3. Use of boxes for nests by various SCNs between 1980 and 1982.

Species	WS-17			Number of Boxes Used WS-8			WS-13		
	1980	1981	1982	1980	1981	1982	1980	1981	1982
Violet-green Swallow	0	0	5	0	4	9	0	1	1
Mountain Chickadee	0	0	1	0	2	1	0	1	2
White-breasted Nuthatch	0	0	1	0	0	1	0	0	0
Pygmy Nuthatch	0	2	2	3	5	5	0	0	2
House Wren	0	1	0	0	0	0	0	0	0
Western Bluebird*	3	10	15	3	11	9	0	2	3

*Boxes used twice for first and second broods are counted only once.

Considerable variation between species was found in nesting success. Pygmy nuthatches had the highest nest success whereas Western Bluebird second nests were the least successful. Nesting success was approximately equal on the three plots but did vary between years. For example, overall Violet-green Swallow success was about 35% lower in 1982 than 1981. Such variation appears to be due to annual differences in spring-summer precipitation and temperature and breeding phenology (Brawn and Balda, in prep.).

The primary cause of nesting failure was abandonment of either unhatched eggs or nestlings. It is unlikely that predation on breeding adults was responsible for these abandonments since, in the cases where birds were color marked, breeding adults were subsequently observed on the plots.

Predation on eggs or nestlings occurred in only 4 out of the 110 nests (4%). This rate of predation is much lower than that reported for many cavity nesters (Ricklefs 1969). We are not certain of the identity of the predator but, based on conditions of the nests, we consider gopher snakes (*Pituophis melanoleucus*) a possibility. All the predation losses occurred on Western Bluebird second nests in 1981. Thus, no "build-up" of predation pressure has occurred on any of the plots.

Table 4. Overall nesting success of SCNs in nest boxes.

Species	Number of Nest Attempts	Number of Successful Nests (%)
Violet-green Swallow	21	12 (57)
Mountain Chickadee	7	6 (86)
White-breasted Nuthatch	2	1 (50)
Pygmy Nuthatch	18	17 (94)
House Wren	1	1 (100)
Western Bluebird		
First Nests	38	30 (79)
Second Nests	23	13 (43)
Totals	110	80 (73)

Nest parasites were not found to be an important source of nesting failure. The only nests in which we found parasites were second nests of Western Bluebirds (N = 9, 39%). The parasites were blowfly larvae of *Apaulina* (formerly *Protocalliphora*). We found no relationship between incidence of parasitism and probability of nest success or nesting mortality ($P > 0.05$, χ^2).

Non-Avian Use of Boxes

Non-avian use of the boxes by vertebrates was limited. Between 1980 and 1982 we found direct evidence of only 1 mammal nest; the species was unidentified. During fall cleanout of boxes we did find several instances of leaves placed on top of old bird nests, but no animals were found. Importantly, mammalian use of the boxes has had very little effect on avian use. Other box projects, designed for birds, have had considerable mammalian use of boxes, particularly flying squirrels (*Glaucomys* spp.) (Brawn 1979)⁴.

Cost of Boxes

The cash outlay and labor necessary to start and maintain the box project have been reasonably low (table 5). The boxes, including shipping from W. Germany, cost less than \$10.00 each. The only equipment necessary to install the boxes were a ladder and hammer.

Labor needed to maintain the boxes was not excessive. To date, after 540 box-years, 2 boxes, which were struck by lightning, have had to be replaced. One other box was removed from its hanger by persons unknown and was replaced. Boxes used for nesting were cleaned out after the breeding period. Cleaning required about 1 man-hour/box.

Other workers have recommended against nest box programs because of prohibitive costs. For example,

⁴Brawn, J.D. 1979. The relationship of cavity nesting birds to snags in the oak-hickory forest. Unpub. Masters Thesis. Univ. of Missouri-Columbia, Columbia, Missouri.

McComb (1979)⁵, with regards to southeastern forests, reports 4 to 14 cavities must be present before one is used by a cavity-dependant species. Citing a cost of \$25.00/box it was determined that a minimum of \$100.00 was necessary for each active box.

Our findings, however, indicate that such caution is unwarranted in ponderosa pine forests. Our data clearly demonstrate that the costs/active box are considerably less. For example, by 1982 we found that about 1 box in 3 (on WS-8 and WS-17) were used. This does not indicate, however, that 3 boxes are needed for every one used by SCNs. Differences in territorial behavior (between species), yearly fluctuations in density of prospective breeders, climate, and habitat type are likely most responsible for much of the variation in box usage. Moreover, preliminary analysis of the 1983 breeding season indicates that box usage will again increase; thus lowering the expense of boxes in terms of cost/active nests.

CONCLUSIONS

The results of this study demonstrate that boxes are a viable management option for SCNs in ponderosa pine habitat but that extant snag-density will markedly effect how often and what uses boxes. On stands such as WS-13 it is clear that the installation of boxes is unnecessary. On stands with few snags, boxes will be used but the response is also mitigated by structure of live vegetation. For example, we found that very open areas, like WS-17, will support fewer foliage gleaners, such as Pygmy Nuthatches, than areas like WS-8 which have higher foliage volume.

Maintenance of densities of snags sufficient to locally maintain cavity-dependant species of wildlife has been recommended by many workers. We stress that snags will always be needed in ponderosa pine forests. Many species that require snags do not use nest boxes. Boxes cannot be considered as a complete substitute for snags but should be considered as part of the solution to maintaining snag-dependant fauna. No management plan for cavity nesters should depend on only one technique or policy. An integrated approach will in the long term likely be the most effective.

Finally, our data show that many oft-cited reasons for not using boxes can be irrelevant. We found neither predation or parasitism were factors that should prohibit use of boxes. Costs in our study were not prohibitive; however, expense will be quite likely variable depending on such aspects as box design used and scale of the project. We suggest that pilot box programs be initiated in other habitat types so that the efficacy of such an approach can be assessed. In the ponderosa pine forests of northern Arizona, boxes work and cannot be ignored as an effective management option.

⁵McComb, W.C. 1979. Nest box and natural cavity use by wildlife in mid-South hardwoods as related to physical and microclimatic characteristics. Ph.D. Thesis, Louisiana State Univ., Baton Rouge, LA.

Table 5. Cost and labor for nest box project.

Item	Cash Outlay and/or Labor
Boxes, hangers, and shipping	\$9.30/box
Installation (transport of boxes to plot, selection of box trees, and installation)	2 man-hours/box
Maintenance (cleaning 1 time/year)	1 man-hour/box

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A Palo Verde Snag in the Sonora Desert¹

Charles E. Kennedy²

Abstract.--Nearly constant daily use of a dead little-leaf (Yellow) palo-verde (Cercidium microphyllum) in the Sonoran, Saguaro Palo Verde Desert by 13 species of birds is discussed. The bird species are listed with some discussion regarding their behavior in the snag.

INTRODUCTION

The snag being discussed here is approximately 15 feet tall, 6 inches in diameter at breast height, and has a crown spread of 12-18 feet, is hard, and has no cavities. It occurs with other typical Sonoran desert vegetation such as mesquite (Prosopis juliflora), blue palo verde (Cercidium floridum), and saguaro (Carnegie gigantea). Shrubs in the area include creosote bush (Larrea tridentata), white thorn (Acacia constricta), and sweet acacia (Acacia farnesiana) (some of which are introduced ornamentals). Other acacias and mimosas are in the general area, but are not common near the snag. The most common shrub near the snag and within the general vicinity is burr sage (Franseria dumosa).

In addition to the saguaros (approximately one per acre) several species of cacti are present. Engelmann prickly pear (Opuntia engelmannii), jumping cholla (Opuntia fulgida), and barrel cactus (Ferocactus wislizenii) are common.

Grasses are rather uncommon. No perennial grasses have been observed. Six weeks grama (Bouteloua barbata) is a common annual grass.

Snags are uncommon in the Sonoran Desert. In a recent survey of vegetation of 2,100 acres in nearly identical Sonoran Desert type, approximately 12 miles east, no snags were observed. Occasional dead branches were seen on palo verde trees.

The snag is at 2400' elevation. Saguaro densities increase a quarter of a mile away, only a few feet higher (2450-2500). Mesquite and palo verde are larger along the drainages. The soil type is Paleorthid, often is very hardened, and overlays Caliche (Petrocalcic). Five to eight acres west of the snag are undeveloped,

with native vegetation as described above (with the exception of my house--150 feet from the snag). In general, the area is only partially developed. It is an area of northwest Tucson, just west of Oracle and Orange Grove which growth skipped over. Large acreages held by a few owners prevented development.



Figure 1.--This dead palo verde has been used by nine bird species.

¹Paper presented at the Snag Habitat Management Symposium. (Flagstaff, Arizona, June 7-9, 1983)

²Charles E. Kennedy is Wildlife Biologist, Coronado National Forest, Tucson, Ariz.

³Personal communication, Dr. Steve Carothers, 1983, Flagstaff, Ariz.

DISCUSSION

Methods

This paper is based on casual observations of the use of the snag. The observations have been made on impulse at no precise time or period of time.

A few months ago we began listing species seen in the snag and later added to this by noting what species were seen together.

Seasonal Use and Daily Use

No obvious patterns have been detected. Seasonally, use in the spring months appears to be a little lower than summer, fall, and winter. This may be due to time spent in reproduction activities.

Daily uses are rather constant. The snag has a bird or birds more often than the rare times when it is empty.

No aggressive-intolerant behavior between species was observed. All species seem to tolerate each other. Six species were observed together at one time. Twelve individuals--four species--were observed at one time.

Implied Behavioral Uses

Loafing appears to be the most common behavior among nearly every species. Doves, starlings, and finches rest-loaf commonly.

Cactus wrens, thrashers, gila woodpeckers, and cardinals may be resting/loafing during their visits, but stay is nearly always short. They always seem to be too busy to sit for very long.

Gambel's quail occasionally loaf and sit. Males call from tip top perches occasionally, sometimes when alone, sometimes when with a female. Up to six quail have been together loafing.

Food and Water

Water and bird seed are available near my house, 120 feet from the snag. This may influence

Table 1.--Findings and opinions.

Bird Species	Frequency of Use
Mourning dove	Most frequent
House finch	Very frequent
Starling	Very frequent
Cactus wren	Frequent
White winged dove	Frequent (when present ¹)
House sparrow	Frequent
Gambel's quail	Occasional
Gila woodpecker	Occasional
Curve-billed thrasher	Occasional
Anna's hummingbird	Occasional (when present ²)
Cardinal	Infrequent
White crowned sparrow	Infrequent
Boat-tailed grackle	Infrequent
Cooper's hawk	One observation-immature spring migrant

¹Not present in winter.

²Observed during winter months.

the use of the snag, but since the snag was used prior to our supplying feed and water, and the presence of other available water nearby, I do not feel it has any significant effect upon the amount of use of the snag by birds.

SUMMARY AND CONCLUSIONS

1. A snag in a partially developed Sonoran desert type is used regularly by 9 species of birds.
2. The snag has values as a loafing/resting perch for the birds.
3. Regular and scheduled observations would better identify competition and/or intolerance between species and within species, and provide precise data on seasonal and diurnal uses.
4. Persons who like to see birds and have them around, could install a dead standing tree.

Cavities in Trees in Hardwood Forests¹

Andrew B. Carey²

Abstract.--The effectiveness of forest management in ensuring viable populations of cavity-using wildlife will depend on the extent to which managers understand the nature of the cavity resource and the patterns of abundance of cavity trees. To gain such an understanding for Appalachian deciduous forests, I sampled 31 oak-hickory stands (47-120 years old) and 12 maple-beech-birch stands (61-206 years old). Over 4,400 trees were measured to describe the stands and more than 80 ha containing 39,000 trees were searched for cavities. Abundance of trees with cavities was highly variable even among very similar forests; much of the variability was unrelated to age, diameter at breast height (d.b.h.), site index, or other stand or topographic features. Random processes played major roles. Standing dead trees peaked at 50-70 years. Cavity tree abundance (4-9/ha in the oak-hickory, 4-17/ha in the maple-beech-birch) was lower than called for by current management recommendations. Snags (dead or partly dead trees) were more abundant than currently recommended; the value of snags in evaluating habitat is questionable. The two forest types differed markedly in the types of cavity trees, abundance of different kinds of cavities, and the types of management activities that would be appropriate.

INTRODUCTION

Formation of cavities begins when a tree or part of a tree dies, is killed, or is injured. Death or injury can be due to suppression, fire, insect attack, disease, mechanical injury (from wind, snow, ice, falling trees, or other forces), or chemical injury (herbicides, acid rain, and other sources). Invasion by microorganisms sets the stage for decay causing fungi. Decayed wood may be removed by vertebrates; woodpeckers often excavate sound wood to reach columns of decay in trees. Cavities are sometimes formed without intervention by vertebrates; for

example, when a large limb is torn from a tree or when heart rot and invertebrate activity results in hollow trees or limbs (Carey and Sanderson 1981).

Because of the diverse causes of mortality and the diverse species of animals that help create cavities, cavities are formed in many species and many sizes of trees throughout the development of a forest after a regenerative disturbance. More than 60 species of Appalachian birds and mammals use cavities for nesting, roosting, escaping, loafing, eating, or caching food. And cavities in trees are integral habitat elements, necessary for maintaining populations for 23 common, widespread species in central Appalachia (Carey and Healy 1981).

Once formed, a cavity may be used by a succession of invertebrates and vertebrates. John Gill³ observed the use of a black walnut

¹Paper presented at the Snag Habitat Management Symposium, Northern Arizona University, Flagstaff, 7-9 June 1983.

²At the time the research reported was done, Carey was research wildlife biologist, Northeastern Forest Experiment Station, USDA Forest Service, Morgantown, W.Va. Currently he is research coordinator, Old-Growth Forest Wildlife Habitats Program, USDA Forest Service, 3625-93rd Ave. S.W., Olympia, Wash. 98502.

³Gill, J. D. 1983. Personal correspondence. USDA Forest Service, Northeastern Forest Experiment Station, University of Massachusetts, Amherst, Mass. 01003.

(Juglans nigra) in West Virginia over a 32-month period. Initially, a cavity in the tree was being used by honey bees (Apis mellifera). A pileated woodpecker (Dryocopus pileatus) excavated new openings into the tree (suggesting carpenter ants [Campanotus sp.] were also present). Two northern flickers (Colaptes auratus) fed in these openings; then a gray squirrel (Sciurus carolinensis) bore and raised a litter in the newly opened cavity while the beehive persisted. The bees and squirrels used the same entrance. The next year a fox squirrel (S. niger) raised a litter in the cavity; the same year another gray squirrel raised a litter in the cavity. Later a Virginia opossum (Didelphis virginiana) was observed in the cavity. The last use observed (May 1983) was by a fox squirrel that apparently will produce the fourth litter in the cavity. Such sequential, interspecific use of cavities is common, as is interspecific competition for cavities; Carey and Sanderson (1981) provided a brief review.

Much has been written about the characteristics and uses of cavities, trees containing cavities, and the environments of cavity trees used by various species of wildlife; recent reviews were done by Bull et al. (1980), Carey and Sanderson (1981), Conner (1978), Evans and Conner (1979), Hardin and Evans (1977), McComb and Noble (1981), Miller and Miller (1980), Miller et al. (1979), Scott et al. (1980), and Weigl (1978). Species vary in their ability to use cavities, trees, and environments according to their morphology, physiology, behavior, experience, and the presence of other species. Some species, especially secondary cavity-users are very plastic; others, especially some of the cavity excavators, are rather inflexible. For example, southern flying squirrels (Glaucomys volans) use a wide range of cavities (and sometimes other shelters) in many kinds of trees and in many different environments, but pileated woodpeckers are constrained by their size alone to excavating cavities in large trees. It is important to recognize that the cavities and trees used by a species will vary with environment and that many species use what is available, for example, hollow trees, cavities in tree butts, cavities in stumps, and cavities that provide little protection from the elements. Dennis (1969) provided some good examples. It is equally important to recognize that success in rearing litters or raising broods is partially a function of the quality of cavities and cavity trees. It is apparent that animals using poor quality cavities are much less likely to contribute to sustaining their species' population than individuals to which more secure cavities are available. It is, therefore, difficult to formulate an operational (applicable to management goals) definition of cavity or cavity tree.

A cavity is easily defined in a functional sense: a hole in a tree that provides shelter from the elements and protection from disturbance by predators and competitors. I used this functional definition to formulate an operational definition and classification of cavities from a habitat management view: a hole in a tree more than 1 m above the ground (anything lower is readily accessible to snakes and other terrestrial predators) that provides overhead shelter from precipitation (that is, an entrance not facing upward), has no cracks or openings except the entrance, and is in a tree sound enough to withstand normal winds and other mechanical forces. Hollow trees would not be deemed to contain cavities unless there appeared to be cavities in limbs; rather, hollow trees would be considered to be "escape" structures fulfilling only part of the functions of a cavity. Openings to the butt of trees, large cracks in trees, cavities in stumps, and cavities in small, fragile, rotten trees would also be excluded by the definition. Cavities could be classified by size of entrance: small, suitable for small mammals such as deer mice (Peromyscus maniculatus) and southern flying squirrels or small birds such as the black-capped chickadee (Parus atricapillus), tufted titmouse (Parus bicolor), and white-breasted nuthatch (Sitta carolinensis) (these would include cavities excavated by downy woodpeckers, Picoides pubescens); medium, such as cavities commonly used by gray squirrels or excavated by woodpeckers such as the red-bellied woodpecker (Melanerpes carolinus) and hairy woodpecker (Picoides villosus); and large, cavities that could be used by raccoons (Procyon lotor) or owls. Cavities can be cross-classified by use: mammal, with fresh gnawing or nest of leaves; bird, such as recently excavated woodpecker cavities; and bird or mammal, with no evidence of what is presently using it. Actual dimensions and the nature of the cavity entrance and the cavity tree could be used to guess how the cavity was formed and the species that might be using it; but, unless the occupant is seen, a cavity cannot be assigned to a particular species.

Most surveys of cavities in trees have concentrated on describing the cavities and cavity trees used by particular species of wildlife such as gray squirrels or pileated woodpeckers, or by groups such as woodpeckers or secondary cavity-using birds. Only a few surveys have tried to determine the abundance of cavities in deciduous forest (Boyer 1976, Dalke 1948, and Gysel 1961). My purpose in this paper is to describe the variety and abundance of cavities in second-growth hardwood forests in West Virginia, and to provide managers with a better understanding of the cavity resource.

METHODS

Study Areas

Oak-Hickory Forest

My study area was a 2-km-wide strip across the approximate center of Middle Mountain in the Monongahela National Forest in Greenbrier and Pocahontas Counties, West Virginia. The mountain is a ridge 29 km long and 2.4 to 4.0 km wide. The ridge meanders north-northeast and the flanks are dissected by narrow, steep drainages (Gill et al. 1975). The study area was 725-1,024 m in elevation and encompassed 17 mixed oak stands (53-120 years old, 303 ha), 12 pine-oak stands (47-101 years old, 324 ha), 1 white pine (*Pinus strobus*) stand (53 years old, 13 ha), and 1 pitch pine (*P. rigida*) stand (80 years old, 13 ha). The weighted (by area) average stand age was 76 years, and the average stand size was 20 ha. Site index (northern red oak) ranged from 36 to 85 with a weighted average of 43; 20 stands were classified as low quality, 10 as immature, and 1 as two-aged for timber management purposes.⁴

Maple-Beech-Birch Forest

The maple-beech-birch stands were in the Cheat Ranger District, Monongahela National Forest, in Randolph and Tucker Counties, West Virginia. Seven stands were 61-69 years old and 5.7-38.9 ha; four stands were 94-126 years old and 13.0-37.7 ha; and one stand was 206 years old and 27.5 ha. Site index for northern red oak ranged from 70 to 80. The stands were scattered and on Shavers Mountain, Backbone Mountain, McGowan Mountain, and Bickle Knob.

Stand Selection

The oak-hickory stands were those intersected by or located between 4 of 57 permanent, parallel transects that cross the main ridge of Middle Mountain. The 57 transects were randomly located perpendicular to the main ridge, 0.4 km apart; the starting point of each transect was also randomly located within 40 m of the Forest Service property boundary. The four transects were chosen because they were at the center of the mountain, at its widest point, and away from recently harvested or burned areas, and because of their proximity to field quarters.

The maple-beech-birch stands were chosen by examining the old stands (100+ years) listed in the district's inventory. Only stands without a record of timber improvement activities were examined. Stands that appeared to have had extensive human disturbance were

avoided. Because undisturbed old stands were few in number, almost all were studied. Younger undisturbed stands were selected in the vicinity of the old stands.

Almost every stand we visited had at least minor evidence of disturbance, such as selective cutting, grapevine control, or felled trees. Many had trees of two age classes: the predominant class determined by the last harvest and a small number of trees left during the harvest. The oldest oak-hickory stands were located on ridges and poor sites; the best of the old stands had been cut. Nevertheless, the stands chosen for study are representative of the hardwood forests on upland sites in West Virginia as they exist now, but neither the oak-hickory nor the maple-beech-birch stands were a true random sample. Because of the preferential selection, minor disturbances, and bias (old stands on the poor sites), nominal statistical levels are not very meaningful, and I interpreted the results with all of the above in mind.

Sampling Methods

Sampling the Forest

The point-centered quarter (PCQ) method (Cottam and Curtis 1956) was used to sample trees larger than 10 cm d.b.h. every 20 m along 3 km of each of the four transect lines on Middle Mountain and along the long axes of the maple-beech-birch stands. Additional transect lines were placed in the old stands on Middle Mountain. The distance from the PCQ point to each tree was recorded along with tree species, d.b.h., crown class (dominant, subdominant, or suppressed), number of dead branches greater than 8 cm in diameter, and vigor (good or bad depending on the condition of the crown). Other categorical (yes-no) variables were: live; exposed dead wood on trunk; sound sapwood; rot (as evidenced by branch stubs, old wounds, fire scars, broken tops, fungal conks, etc.); woodpecker feeding (as evidenced by torn bark, excavated wood, peckmarks, but not yellow-bellied sapsucker [*Sphyrapicus varius*] sapwells); and woodpecker cavities. All sampling was done during winter because deciduous trees are leafless during winter and visibility is good.

Map Features, Age, and Site Index

I located each oak-hickory sampling point on U.S. Geological Survey topographical maps. For each point I recorded the elevation, the relative elevation (elevation divided by the elevation of the highest point in the study area), the major aspect (sine of the aspect of at least two contour lines), and the position on the mountain slope (the distance from the point to the valley floor divided by the

⁴ White Sulphur Springs Ranger District, Monongahela National Forest. Compartment records, unpublished. White Sulphur Springs, W.Va.

distance from the ridgetop to the valley floor). Age of stand and site index were taken from Forest Service stand inventory data (see footnote 4).

RESULTS

Oak-Hickory Forest

PCQ Sample

Describing Trees With Cavities

I prepared for cavity-searches by doing a pilot study in maple-beech-birch stands. Eight 25- x 40-m plots were searched for cavities, and the 915 trees in the plots were cut down. Each tree was cut into sections and examined for cavities (Carey and Healy 1981). On this basis we felt we could conduct cavity-searches by examining trees from the ground with binoculars.

Cavity trees were sampled by searching 30-m wide strips centered on the transect lines. One observer walked the line while two others walked abreast of him, 15-20 m away on either side of the line. Binoculars were used to search all trees in the strip for cavities. Upon sighting a hole in a tree, the observer would attempt to find a position from which he or she could inspect the hole through binoculars to determine its potential and probable uses. Rangefinders were used to determine if borderline trees were within or outside the strip. The PCQ and following variables were recorded for each tree deemed to contain a cavity that offered a bird or mammal secure shelter: upright or pronounced lean, top intact or top broken, and number of decayed branches, stubs, or scars of branches thought to have been 8 cm or more in diameter. In addition, each tree was categorized (yes-no) as a feeding snag (extensive woodpecker feeding), an escape tree (a large hollow in the tree), or as containing a bird's cavity, a small mammal's (gray squirrel-size or smaller) cavity, and/or a large cavity. A description of each cavity found was recorded.

Statistical Methods

Preliminary examination of the data was accomplished using the SAS (Helwig and Council 1979) and BMDP (Dixon 1981) computer programs for summary statistics, histograms, bar charts, and scatter plots. A variety of tests of significance were used: the actual test chosen for any specific comparison was chosen to minimize violations of test assumptions. Differences reported in the text are differences that were statistically significant at $P < 0.01$. The relationship between the abundance of cavities and the stand and topographic characteristics was examined through regression analysis with appropriate transformations (Frane 1981).

Among 2,400 trees in the sample, the most abundant species and their mean d.b.h. were: chestnut oak (*Quercus prinus*), 23 cm; northern red oak (*Q. rubra*), 24 cm; pignut hickory (*Carya glabra*), 22 cm; and white oak (*Q. alba*), 20 cm. Twenty-four other species had relative frequencies of less than 5 percent and made up 34 percent of the trees. Only 57 trees (2.4 percent) had woodpecker cavities; the median d.b.h. of these cavity trees was 38.8 cm, whereas the median d.b.h. of all trees was 18.1 cm and only 25 percent were larger than 27.7 cm. Cavity trees tended to be dominant in the canopy (39 percent) or suppressed (42 percent). Only 19 percent of the total sample were dominants; 42 percent were codominant and 39 percent suppressed. The cavity trees were, on the average, 75 percent larger with three times more dead branches than the average tree (table 1). The proportion of trees with rot, evidence of woodpecker feeding and/or poor vigor, was also greater for trees with woodpecker cavities than for the entire sample; likewise, a greater proportion of cavity trees were dead or partly dead (table 1). The largest trees (38.2 percent of trees greater than 42.5 cm d.b.h.) were chestnut oaks; a disproportionate share of the cavities was in chestnut oaks. A even greater disproportionate share of cavities was in black locusts (*Robinia pseudoacacia*), most of which were suppressed (65 percent), poor in vigor (68 percent), or dead (46 percent); 89.5 percent had rot; and mean d.b.h. was 21.0 cm.

Strip Transect Sample

Thirty-six hectares were searched for cavities along the PCQ transect lines. This area included an estimated 19,161 trees, 235 (1.2 percent) of which were identified as containing cavities. Although the transects were remarkably uniform in tree species composition, and were not different ($P > 0.10$) in mean d.b.h. and density of trees, the density of cavity trees varied between five and nine per hectare. The mean d.b.h. of cavity trees was 41 cm, almost twice the mean for the PCQ sample; 80 percent of the cavity trees were dominants (versus 19 percent of the PCQ sample). Trees containing gray squirrel cavities were larger still, averaging 50 cm d.b.h. (table 2).

The species composition of cavity trees was: chestnut oak, 44 percent; northern red oak, 19 percent; black locust, 10 percent; white oak, 9 percent; and pignut hickory, 7 percent. Ten other species also had cavities. As with the PCQ sample, a disproportionate share of the cavity trees were in chestnut oaks (104 trees, mean d.b.h. 43.4 cm) and black locusts (23 trees, mean d.b.h. 26.1 cm). Of

Table 1--Characteristics of trees with woodpecker-excavated cavities, Middle Mountain, West Virginia, 1980¹

Variable	Trees with cavities	All trees
Sample size	57	2400
D.b.h. ($\bar{x} \pm SE$, cm)	37.9 + 1.8	21.7 + 0.2
Range in d.b.h. (cm)	13.3 - 76.0	10.0 - 105.2
Dead branches/tree ($\bar{x} \pm SE$)	0.7 + 1.2	0.2 + 0.6
Percentages of trees:		
With dead branches > 8 cm in diameter	37	9.5
Alive	68	93.8
Vigorous	60	84.0
With rot ²	97	54.8
Partly dead ³	74	23.0
With woodpecker feeding	91	38.7
Chestnut oak	42	30.3
Black locust	14	2.4
Northern red oak	9	15.1
White oak	9	9.9
Pignut hickory	4	11.2

¹Data were collected from 600 point centered quarter sampling plots.

²As indicated by fungi, wounds on the bole, fire scars, cracks, holes, and large dead-branch stubs.

³Exposed dead wood on bole.

Table 2--Characteristics of all trees and cavity trees, both >10-cm DBH on Middle Mountain, West Virginia¹

	TRANSECT				
	1	2	3	4	$\bar{x}$
Age (years) ²	74	74	69	72	72
Basal area (m ² /ha)	19	21	20	19	20
N/ha					
All trees	546	514	521	548	532
Cavity trees/ha	5	8	9	5	7
Average DBH (cm)					
All trees	21	23	22	21	22
All cavity trees ³	39	41	42	44	41
Squirrels	51	54	48	46	50
All mammals	39	46	48	46	44
Birds	35	39	38	47	40

¹Data on all trees from 600 PCQ plots; on cavity trees, from 36 ha of strip transects.

²Weighted by area of stand intersected by transects.

³Compare d.b.h.'s of all cavity trees with those below: squirrel-den trees, those probably used by some mammal, and by some bird.

the black locusts, 57 percent were suppressed and 39 percent were dead.

The 235 cavity trees contained 134 cavities potentially useful to birds, 155 to mammals, and 22 to large vertebrates (table 3); 16 percent of the trees were dead, and 12 percent were hollow. Trees containing bird cavities differed from trees containing mammal

cavities in that more were dead, more had broken tops, and their mean diameter was smaller. But 48 percent of trees with bird cavities also had mammal cavities, and 41 percent of trees with mammal cavities also had bird cavities (table 4). Trees with large cavities had a mean d.b.h. of 58.7 cm (SE = 3.2 cm); all were alive, but 23 percent had broken tops.

Table 3--Numbers, kinds, and selected features of cavity trees among all trees > 10-cm d.b.h. on transects across Middle Mountain, West Virginia

Characteristic	-- -- -- -- --TRANSECT -- -- -- --				Total
	1	2	3	4	
All trees (N)	4,914	4,626	4,689	4,932	19,161
Cavity trees:					
Number	46	71	77	41	235
Prevalence ¹	9.4	15.3	16.4	8.3	12.3
Trees ² with:					
Bird cavities	28	50	35	21	134
Mammal cavities	30	39	53	33	155
Large cavities	1	6	11	4	22
Other features of cavity trees:					
Dead trees	10	14	10	3	37
Feeding snags	19	16	17	26	78
Hollow trees	6	3	5	14	28
Dead branches/live trees	1.3	1.4	1.2	1.6	1.4

¹Cavity trees/1000 trees greater than 10 cm d.b.h.

²Some trees had more than one cavity. Cavities are loosely classified by potential or probable use: bird, woodpecker cavities and other cavities with entrances less than 5 cm in diameter; mammal, gray squirrel cavities and cavities with entrances less than 5 cm in diameter; large, all cavities with entrances larger than 10 cm.

Table 4--Categorical comparison of bird- and mammal-cavity trees on Middle Mountain, West Virginia

Characteristic	Mean		Range	
	Bird	Mammal	Bird	Mammal
-- -- -- -- --Percent -- -- -- -- --				
Alive	70	95	46-86	87-97
Dead and hard	12	5	9-14	3-13
Dead and soft	8	0	0-16	-
With dead branches ¹	58	78	41-76	69-94
With broken tops	31	22	23-38	18-30
Hollow	14	16	2-38	5-39
With mammal cavities	48	--	35-72	-
With woodpecker cavities	50	--	36-57	-
With bird cavities	--	41	-	30-49
With gray squirrel dens	--	46	-	20-64
Cavities/tree	1.9	1.7	1.6-2.3	1.4-2.2
D.b.h. ratio ²	1.8	2.1	1.6-2.2	1.9-2.2

¹Dead branches were recorded as present on live trees only.

²D.b.h. of cavity trees/d.b.h. of PCQ trees.

A Sample of Older Stands

Five stands 101-120 years old were sampled. Most were on ridges and were composed of widely-spaced older trees with a second age class of younger trees developing. These stands were similar to those on the transects in species composition, basal area, and mean tree d.b.h. (table 5). But cavity trees were less numerous and larger than those along the transects; 41 cavity trees were found, for a density of 4 per hectare. The trees averaged 46 cm d.b.h. and 31 had mammal cavities, 21 had bird cavities, and 8 had large cavities. Twelve were hollow, and 6 were dead.

Regression Analysis

It was necessary to transform cavity tree abundance by taking the square root of the observations to achieve normality in the dependent variable. Independent variables considered were mean d.b.h., standard deviation of d.b.h. (as a measure of residual trees), tree density, position on the mountain slope, elevation, aspect, site index, and age of stand. Data were from 132 80- x 30-m plots along the transect lines. Cavity tree abundance (averages of two sampling plots) averaged 1.48 and ranged from 0.0 to 6.5. Site index averaged 56 and ranged from 36 to 80. The d.b.h. averaged 22 cm and ranged from 14 cm to 32 cm. Regression analysis using the all-possible-subsets methods indicated that the

best single predictor was d.b.h. ($R^2 = 0.11$), and the two best predictors were d.b.h. and site index ($R^2 = 0.14$). Additional variables raised the correlation coefficient but the coefficients of the additional variables were not different ($P > 0.10$) from zero. Although the correlation coefficient of the regression on d.b.h. and site index was low, the regression was significant ($P < 0.0000$). The residuals of this regression had a mean of zero, were normally distributed, and were not correlated with either independent variable or with the predicted values of the dependent variable. I, therefore, concluded that much of the variability in cavity abundance was random and could not be accounted for by topographic position, site index, or stand characteristics (age, d.b.h., variability in d.b.h., and tree density). Discrete multivariate analysis of categorical variables (tree species, forest type, d.b.h. class, etc.) was more successful but required a number of tree-specific measurements. Those results will be reported elsewhere.

Maple-Beech-Birch Forest

PCQ Sample

All age classes were dominated by sugar maple (*Acer saccharum*) and American beech (*Fagus grandifolia*). Yellow birch (*Betula alleghaniensis*), red maple (*A. rubrum*), American basswood (*Tilia americana*), and black

Table 5--Comparison of five older stands (101-120 years) with younger stands on transects

Characteristic	Mean ¹ of mean		Range of mean	
	Old	Transect	Old	Transect
Age (years)	110	72	101-120	69-74
Basal area (m ² /ha)	20	20	15-29	19-21
Trees/ha	596	532	516-772	514-548
Cavity trees/ha	4	7	1-9	5-9
D.b.h. (cm):				
PCQ trees	21	22	16-23	21-23
Cavity trees	46	41	39-52	39-44

¹Weighted by area sampled. Five old stands were sampled by PCQ (424 trees) and by strip transects (12.3 ha) encompassing 26,421 trees. Forty-one cavity trees were found.

cherry (*Prunus serotina*) were common, but less abundant than sugar maple or American beech (table 6). Northern red oak (*Q. rubra*) and 20 other species occurred in relatively low abundance.

The 206-year age class was not different ($P > 0.10$) from the 94- to 126-year age-class in mean d.b.h., tree density (PCQ distance), or dead branches per live tree. The 61- to 69-year class was different from the older classes in mean d.b.h., density, and dead branches per live tree ($P < 0.01$). Note, however, the great variability among stands within the two age classes that had replicated sampling (table 6).

The number of large, dead branches per live tree and d.b.h. increased from young to old age classes. In addition, the density of large, dead branches (table 7) and the proportion of trees woodpeckers used for feeding (table 6) increased with age class.

Large, dead branches were well correlated with d.b.h. ($r = 0.67$). However, the density of trees, including dead trees, decreased with age class.

Cavity Search

In a 44.5-ha area, 459 trees with cavities were found out of an estimated 20,181 trees. Density, prevalence, and mean d.b.h. of trees with cavities increased with age (tables 7 and 8). The percentage of cavity trees that were dead or hollow decreased with age. The percentage of trees with cavities used by mammals was consistently much larger than the proportion with cavities used by birds (table 8). Large cavities were rare: only 15 were found.

Practically all species of trees had cavities, but the relative importance of species varied with age. In the oldest stand,

Table 6--Characteristics of three age classes of maple-beech-birch forest in Randolph and Tucker Counties, West Virginia¹

Characteristic	Stand age-class		
	61 to 69 years (7 stands)	94 to 126 years (4 stands)	206 years (1 stand)
Predominant species ²	Sugar maple American beech Red maple	Sugar maple American beech Yellow birch	Sugar maple American beech American basswood
Trees/ha:			
Mean	542	386	374
Range	333-854	354-445	-
Median d.b.h.: ³			
Mean	24	28	29
Range	19-29	25-30	-
Dead branches/live tree:			
Mean	0.45	0.72	0.88
Range	0.24-0.72	0.35-0.94	-
Percentages of trees:			
Dead	10	11	6
Partly dead	28	30	28
With rot	76	84	77
With woodpecker feeding	27	33	52
With woodpecker cavities ⁴	3 (0-16)	2 (0-4)	14

¹Based on a sample of 12 stands and 2,000 trees chosen by point centered quarters.

²Listed in order of relative importance.

³Mean d.b.h. means (and ranges): young, 28 cm (24-29 cm); old, 31 cm (29-33 cm); oldest, 31 cm.

⁴Ranges in parentheses; in one young stand, 16 percent of the trees were cavity trees; the other six stands averaged 1 percent.

Table 7--Cavity tree, dead branches, and dead tree density
by age class of maple-beech-birch forest in Randolph
and Tucker Counties, West Virginia

Characteristic (per ha)	Stand age-class		
	61 to 69 years (7 stands)	94 to 126 years (4 stands)	206 years (1 stand)
Cavity trees: ¹			
$\bar{x}$	9.8	10.3	13.3
SE ($\bar{x}$)	1.7	0.9	--
Range	4.5-16.8	7.9-11.8	--
Dead branches: ²			
$\bar{x}$	247.4	283.2	327.0
SE ($\bar{x}$)	49.4	62.4	--
Range	102-445	124-419	--
Dead trees: ³			
$\bar{x}$	55.1	40.7	22.4
SE ($\bar{x}$)	10.7	3.3	--
Range	15-93	32-48	--

¹Area searched: 20.4 ha for 61-69; 18.1 ha for 94-126; 6 ha for 206.

²Trees examined: 1,084 trees for 61-69; 716 trees for 94-126; 200 trees for 206; dead branches were greater than 8 cm in diameter and on live trees.

³Calculated by multiplying density estimates by the proportions of sample trees that were dead and averaging among stands.

Table 8--Characteristics of cavity trees in three age classes
of maple-beech-birch forest in Randolph and Tucker Counties,
West Virginia

Characteristic	Age-class		
	61 to 69 years	94 to 126 years	206 years
Trees examined	10,816	7,123	2,242
Cavity trees:			
Number found	186	193	80
Prevalence ¹	17.2	27.1	35.7
Average d.b.h. (cm):	39.5	53.2	51.9
SE ($\bar{x}$) of d.b.h.	3.0	4.8	2.4
Dead (percent)	29.1	16.0	12.5
Mammal (percent)	82.4	74.4	75.0
Bird (percent)	20.8	25.6	30.0
Large (percent) ²	0.9	9.5	0.0
Escape (percent)	32.8	29.3	18.0

¹Cavity trees per thousand trees.

²Cavity trees containing large cavities.

48 percent of cavity trees were sugar maple (versus 36 percent of PCQ trees), 21 percent were American beech (versus 24 percent of PCQ trees), and 16 percent were red maple (versus 6 percent of PCQ trees). Sugar maples were also predominant in the old stands but not disproportionately (37 percent versus 40 percent). But American beech was disproportionately predominant (29 percent versus 18 percent) as was American basswood (12 percent versus 7 percent). Likewise, in the young stands sugar maple was proportionately abundant and American beech disproportionately so (20 percent versus 13 percent); but eight other species were abundant (comprising more than 10 percent of cavity trees) in individual stands: Fraser magnolia (*Magnolia fraseri*), black locust, pignut hickory, northern red oak, white ash (*Fraxinus americana*), striped maple (*A. pensylvanicum*), yellow-poplar (*Liriodendron tulipifera*), and black cherry.

Use of Cavities

Trees with cavities used by birds were smaller with fewer dead branches, were less abundant, and were more likely to be dead, to be fed upon by woodpeckers, and to have broken tops than trees with cavities used by mammals (table 9). The d.b.h. of trees with cavities

used by birds increased with age class, but the percentage of dead trees with soft sapwood declined (table 10). Thus the number of dead branches per tree increased. The percent of bird-cavity trees used by mammals was greater than the percent of mammal-cavity trees used by birds (table 11). The d.b.h. of trees with cavities used by mammals also increased from young to old, and the percentage that were dead (hard or soft sapwood) declined. Both bird- and mammal-cavity trees averaged more than one cavity per tree (tables 10 and 11). Few of the bird- and mammal-cavity trees had large cavities. All trees with large cavities were alive and were characterized by larger-than-average numbers of dead branches, rotten branch stubs, and large branch scars. The average d.b.h. of trees with large cavities was 57.8 cm (SE = 5.5 cm); six had mammal cavities, two had bird cavities, and six were hollow.

Age and Variability

The young stands were much more variable in all characteristics than the old stands. Given such variability in overall tree density and d.b.h. (table 6) and the abundance of cavity trees, large dead branches, and dead trees (table 7), it is not surprising that cavity tree density and cavity abundance were not well correlated with stand age ($r = 0.23$).

Table 9--Comparison of bird-cavity trees to mammal-cavity trees by age class in maple-beech-birch forests in Randolph and Tucker Counties, West Virginia¹

Characteristic	Stand age-class		
	60 to 69 years	94 to 126 years	206 years
Cavity trees:			
Average d.b.h.	0.7	0.8	0.8
N/ha	0.2	0.3	0.4
Ratios of percentages: ²			
Dead and hard	2.8	8.6	8.3
Dead and soft	39.0	16.0	(8/0) ³
Top broken	2.8	2.4	14.0
Dead branches	0.4	0.7	0.8
Feeding	1.2	2.6	2.8

¹Table values are bird values divided by mammal values.

²Hard and soft refer to sapwood; dead branches includes scars, stubs, and branches greater than 8 cm in diameter; feeding refers to trees extensively fed upon by woodpeckers.

³Among mammal-cavity trees, none was dead and soft.

Table 10--Comparison of cavity trees probably used by birds by age class of maple-beech-birch forests in Randolph and Tucker Counties, West Virginia

Characteristic	Age class		
	61 to 69 years	94 to 126 years	206 years
Cavity trees			
N/ha	33 (1.6)	49 (2.7)	24 (4.0)
Cavities/tree	1.2	1.5	1.4
D.b.h.:			
$\bar{x}$	29.0	44.2	46.0
SE ($\bar{x}$)	3.1	3.8	3.8
Percent of trees: ¹			
Dead and hard	36	43	25
Dead and soft	39	16	8
Tops broken	76	71	29
Dead branches	30	59	63
Percent use: ²			
Mammal	18	22	21
Large animal	3	6	0
Escape	6	16	21
Feeding	39	53	71
Woodpeckers	39	43	21

¹See Table 9 for explanation of categories.

²Escape refers to trees with hollow trunks; woodpeckers to recently excavated cavities.

Table 11--Comparison of cavity trees used by mammals by age class of maple-beech-birch forests in Randolph and Tucker Counties, West Virginia

Characteristic	Age class		
	61 to 69 years	94 to 126 years	206 years
Cavity trees:			
N/ha	159 (7.8)	147 (8.1)	61 (10.2)
Cavities/tree	1.3	1.4	1.3
D.b.h.:			
$\bar{x}$	42.3	57.1	54.4
SE ($\bar{x}$)	2.4	5.6	2.8
Percent of trees: ¹			
Dead and hard	13	5	3
Dead and soft	1	1	0
Tops broken	27	30	2
Dead branches	72	84	80
Percent use: ¹			
Bird	4	7	7
Large animal	0	5	0
Escape	33	43	25
Feeding	20	20	41

¹See Tables 9 and 10 for explanation of categories.

DISCUSSION

Formation of Cavities

In both the oak-hickory and maple-beech-birch forests cavity trees were, on the average, much larger than the average tree. This is expected because of the ways cavities form. Large (and old) trees develop large branches that die and the result is top rot. When small branches die the tree usually heals quickly and, even if decay organisms gain entry to the tree, the decay can be compartmentalized. Large, old trees have a greater probability than small, young trees of having been exposed to fire, wind storms, ice storms, early snowfall, falling trees, insect attack, and other injurious events that result in broken branches, broken tops, or wounds that allow decay organisms to enter the tree. In addition, it takes time for decay to spread, develop, and soften the wood. On Middle Mountain I saw evidence of small fires, wind damage, and death of large branches by natural pruning. In the maple-beech-birch study area, I observed a large amount of damage from ice storms and early snowstorms as well as natural pruning. Leaves still on trees during early snowstorms provided a large surface area that accumulated snow and caused large branches to break. But in both areas, cavities were also found in small trees, particularly black locust and other trees that were suppressed. These small trees accounted for most of the dead cavity trees, especially those with soft sapwood. As the forest develops, mean d.b.h. increases and tree density decreases. The density of dead trees in the young maple-beech-birch stands was 1.4 times the density in the old stands and 2.5 times the density in the oldest stands.

From a wildlife standpoint there are two major processes taking place. The first is the gradual suppression and death of small trees, which results in substrate available for excavation of cavities by species that use dead trees or require soft sapwood. The second process is the exposure of large trees to decay organisms. This results in top rot that provides cavity substrate for species that can excavate through sound sapwood, or can prevent callus from sealing off columns of decay formed by rotting branches. This is not to say that nonexcavators or weak excavators do not use the large, live cavity trees. Pileated woodpeckers created an amazing number of feeding excavations in live trees on Middle Mountain. Many of these were narrowed by callus formation and were used by a variety of species. Other woodpeckers also start and abandon, or create, use, and abandon cavities that are later used by other species. When large, dead branches become soft, they provide the same substrate as small, dead trees. We found very few large, dead trees in either study area. It appeared that most large, old trees died after falling during heavy winds; not while standing. Blowdown of individual trees and patches of mature trees was observed in both areas.

Determinants of Cavity Tree Abundance

The density of cavity trees in the second-growth oak-hickory forest was a function of d.b.h., site index, and random processes contributing to cavity formation (fire, wind, and ice storms). Cavity abundance was variable and was not predictable from stand data and map features. Trees were more abundant, grew faster, and provided more cavities on good sites than on poor sites. None of the sites had been thinned, and it can be assumed that thinning would have reduced the number of small cavity trees.

The density of cavity trees increased with age-class in the maple-beech-birch forest. But especially in the young stands, cavity tree abundance was variable, and probably a function of early stand history--regeneration and initial stocking levels. As in the oak-hickory forest, suppressed trees were important for the development of dead cavity trees; the number of dead trees decreased with age.

The distribution of the d.b.h. of cavity trees compared to the more-or-less randomly sampled trees indicated that a majority of cavity trees were in the upper 25 percent of tree diameters. This, and my personal observations, suggests to me that a significant proportion of the cavity trees were trees carried over from the previous stand. It is hard to age trees with cavities because their cores are usually rotten; however, a small sample of increment cores did confirm that some of the cavity trees predated the regeneration harvest.

Probable Users of Trees With Cavities

Although the density of trees with cavities in the oak-hickory forest was less than the density in the maple-beech-birch forest, a greater proportion of the oak-hickory trees were used by birds. Thus the density of bird-cavity trees was greater in the oak-hickory forest than in the maple-beech-birch forest. The proportion of cavities used by birds that were recently excavated by woodpeckers and the density of woodpecker cavities was also greater in the oak-hickory than in the maple-beech-birch forest. In both forests, bird-cavity trees were more likely to be dead and to have broken tops than were mammal-cavity trees. But this difference was more pronounced in the maple-beech-birch forest than in the oak-hickory; suggesting a greater reliance of birds on suppressed trees in the maple-beech-birch forest. In the maple-beech-birch forest a majority of live cavity trees contained small cavities formed mostly as a result of the natural pruning of branches. These cavities were suitable as dens for deer mice, southern flying squirrels, and red squirrels (*Tamiasciurus hudsonicus*). In the oak-hickory forest many cavities in live trees had been created by the feeding activity of pileated woodpeckers and other woodpeckers and

provided a variety of suitable shelters. I observed little activity by pileated woodpeckers in the maple-beech-birch stands. Likewise, the oak-hickory forest contained over four times as many large cavities as the maple-beech-birch forest. Large cavities appeared to have most often resulted from long use as dens by gray squirrels.

Supply and Demand of Trees With Cavities

The questions of how many cavities are enough and how many cavities would there be under "natural conditions" are difficult to answer. The number of trees with cavities that is enough depends on management objectives. Empirical evidence suggested to Sanderson (1975) that more than 1.2 good quality dens/ha would sustain huntable populations of gray squirrels. I found approximately two gray squirrel cavity trees/ha, and most trees had more than one cavity, suggesting that Middle Mountain provided a more than adequate environment for gray squirrels.

Such goals are not as easily examined for other species that use cavities. Less information is available on population levels of other users relative to densities of cavities and cavity trees. And management goals for nongame wildlife are more difficult to define. One goal of the National Forest Management Act is to ensure viable populations of all native wildlife. The abundance of cavities necessary to accomplish this goal for users of cavities that also use other structures, such as deer mice and raccoons, is unknown. Evans and Conner (1979) listed dependent bird species and calculated "maximum densities" by dividing 100 ha by the average territory size reported in the literature. They then determined the number of snags required to maintain percentages of maximum density. They assumed four snags were required per breeding pair per year and chose a multiplier of 10 snags to ensure the four would be available. Their recommendations translate to a density of 26 snags/ha for the woodpecker species that were present on Middle Mountain and Cheat Ranger District (downy, hairy, red-bellied, and pileated woodpeckers, northern flickers, and yellow-bellied sapsuckers). About 40 percent of the trees in both areas were dead, had part of their trunks dead, or had large dead branches. They provided a density of more than 200 snags/ha in the oak-hickory forest and more than 150 snags/ha in the maple-beech-birch forest--substantially more than the 26 snags/ha suggested by Evans and Conner (1979). Conner⁵ suggested using a more stringent definition of snag: a tree that is dead or mostly dead. There were 33 dead trees/ha in the oak-hickory forest and 22-55

dead trees/ha in the maple-beech-birch forest. These densities produced 1.4 recently excavated woodpecker cavity trees/ha in the oak-hickory forest and 0.8-1.1 woodpecker cavity trees/ha in the maple-beech-birch forest. The data suggests that the oak-hickory supported 54 percent of maximum populations and the maple-beech-birch 31-42 percent; both forests would therefore be rated "fair" on a scale of good, fair, and poor. These over-simplified calculations were performed to reemphasize points made by Conner and Adkisson (1977): it is difficult to determine when a tree is suitable for excavation by woodpeckers; and the extent of decay in a live tree is difficult to determine without dissecting the tree. It is evident that further research is necessary to relate the abundance of users of cavities to forest characteristics. Abundance and variability in abundance by forest characteristics and variability in abundance over a number of years must be known before one can confidently formulate management goals to ensure viable populations. The actual abundance of woodpeckers in the oak-hickory forest was 0.2 birds/ha in the spring in 1981; densities in the maple-beech-birch forest were much less in the spring of 1982 (Carey 1983). The oak-hickory density was 24 percent of maximum--a poor environment for nesting by the standards of Evans and Conner (1979).

Forest Ecology

It is important to view cavity trees and the species that use them not in isolation, but as elements of the forest community. It is also important to recognize that users of cavities are adapted to environments that existed in the past but which are now rare in the eastern hardwood forests. Reviewing what is known about forest development helps to place in the proper context the cavities in trees and the species that use them. Bormann and Likens (1979) provided a useful model of forest development consisting of four phases: reorganization, aggradation, transition, and steady state.

Reorganization begins with a regenerative disturbance and lasts for about 20 years in northern hardwood forests. Most kinds of disturbance occur as continua; for example, wind ranges from mild breezes to hurricanes. Competition, aging, insects, disease, climatic fluctuations, weather (drought, ice storms, early snow), and simple growth make trees more susceptible to the action of physical forces. Minor physical disturbance can make trees more susceptible to subsequent disturbance by breaking limbs, reducing leaf area, and increasing susceptibility to insects and disease. This weakens the tree's competitive position in the forest. At the low end of the disturbance continuum individual trees may fall resulting in a small patch of regeneration. At the other extreme, intensive winds or fires may result in large areas of regeneration.

⁵Conner, R. N. 1983. Personal correspondence. USDA Forest Service, Southern Forest Experiment Station, Nacogdoches, Tex 75962.

Reorganization after disturbance is characterized by an increase in herbs, shrubs, and young trees; dead wood (dead limbs on live trees, standing dead trees, and fallen logs) is at a minimum 20 years after a disturbance (for example, clearcutting). Given the shelter and forage requirements of users of cavities, this phase provides the least hospitable environment.

Aggradation lasts from year 21 to year 170 and is characterized by the development of intermediate to large trees with a few massive trees present. Living biomass increases throughout aggradation, but the amount of dead wood peaks at 50-70 years. This phase provides a favorable environment for those species that can use small, dead trees with soft sapwood (for example, black-capped chickadees) or medium-sized trees with large dead branches and top rot (for example, hairy woodpeckers). Dead wood is as abundant at 56 years as at 170 years; but the amount of dead wood fluctuates between year 56 and year 170. In my studies it appeared that standing dead trees peaked between 50 and year 70 but then declined in abundance and contributed to the fallen dead wood biomass. Although the common wisdom is that the older a forest is, the better it is for wildlife that use cavities, my studies suggest that during aggradation in a managed forest environment an important part of the habitat requirements of some cavity-using wildlife may peak at 50 to 70 years, particularly in the maple-beech-birch forest. Post-regeneration management activities, such as thinnings, which are now being stimulated by demand for firewood (Carey and Gill 1980), may have significant impacts on cavity-using populations.

Towards the end of aggradation, cavity-users such as gray squirrels and pileated woodpeckers would find their optimal environment as characterized by intermediate, large, and massive trees, many of which would be senescent and have top rot. During transition (170-350 years) there is a loss of the old, even-aged dominants and a temporary increase in dead wood.

The steady state forest (older than 350 years) is a mosaic of three states: herb-shrub-young tree, small-intermediate-large tree, and massive tree. The steady state forest provides the optimal environment--the complete range of conditions to which the various species are adapted. The variety of environments in the steady state probably reduces interspecific competition by providing small, dead trees in some patches, large live trees with top rot in other patches, and large, dead trees in still other patches. Obviously the patches differ not only in type of trees containing cavities but also in overall structure and suitability for any particular species.

In forest managed for wood products, a different mosaic results. Two states predominate, the herb-shrub-young tree and the

small-intermediate-large tree. Forest development is truncated at mid-aggradation. This truncation has obvious impacts on cavity-users such as pileated woodpeckers. Because the pileated woodpecker can range widely, the steady state forest probably provides an optimal environment with scattered large trees (or patches of large trees) suitable for cavities and patches containing concentrations of foraging substrate (fallen trees or standing dead trees). Other users of cavities would find favorable environments in or among the individual patches. The present-day second-growth forests mimic, somewhat poorly, the steady state with scattered large trees carried over through regeneration, stands in early aggradation, and trees damaged by fires or introduced diseases. Interspecific competition is probably exaggerated in this environment, due to the greater homogeneity than is found in the steady state. For example, in present-day second-growth forests red squirrels or gray squirrels may compete more intensely with white-breasted nuthatches or black-capped chickadees than might occur in the steady state where cavities are abundant in a greater variety of environments. But the modern (future) intensively managed forest is characterized by complete clear-cutting, control of stocking, fire prevention, and short rotations, potentially depriving most cavity-users of amenable environments.

The historical record of the presettlement eastern deciduous forests is vague. Russell (1983) concluded that forest fires were not frequent in the northeastern United States. Bormann and Likens (1979) reported that destructive major storms were not major recycling factors, but that localized intensive winds associated with storm fronts were important. And small-scale windthrow of single trees to medium patches was (and is) common. Thus the scale of disturbance seems to have been small--occasional small fires and localized windthrow; large fires and major windthrow events were less common.

I have seen no discussion of the role of insects or disease in presettlement forests. Present day forests in Appalachia still show the effects of the chestnut blight: fallen dead trees and gaps filled by oaks, hickories, maples, beeches, or birches (Oosterhuis et al. 1982). The steady state forest, then, is a mosaic of small patches. The present trend of small management units (Roach (1974) recommended 8-12 ha as a silvicultural optimum), as compared to the extensive clearcuttings of the past, should be beneficial to users of cavities.

MANAGEMENT IMPLICATIONS

Cavities in trees constitute a diverse and complex resource just as the species that use them are diverse and respond to their environments in complex ways. Users of

cavities are valuable in several ways; for example, gray squirrels and raccoons are game animals; deer mice and cavity-using birds are insectivorous and help to control deleterious insect populations; rodents (including deer mice, flying squirrels, and gray squirrels) are essential for the dissemination of hypogeous ectomycorrhizal fungi that are essential to tree growth; cavity-using birds are important objects of study to birders, naturalists, and the general wildlife viewing public; the wildlife contributes to the aesthetic qualities of the forests; and many cavity-users (especially gray squirrels and woodpeckers) are essential for the creation and maintenance of cavities. But even with these many values it is difficult to formulate precise management objectives. On national forests, one objective and one management constraint are common. The objective is to maintain huntable populations of gray squirrels (or fox squirrels); the constraint is to ensure minimum viable populations of native wildlife. The results of this study, therefore, will be discussed in the light of the objective and the constraint.

Oak-Hickory Forest

Abundance of Trees With Cavities

Abundance of trees with cavities varied almost two-fold in environments that did not differ in species composition, age, mean d.b.h., density, or basal area. Therefore mean cavity tree abundance by age-class is insufficient information on which to base management. Variability in cavity tree abundance must be taken into account in determining areas of age classes to be managed for users of cavities. If only mean abundances are used, the chances that management objectives would not be met are great. Evaluation of habitat to choose stands with high abundances of trees with cavities could be used to reduce the area required to maintain viable populations of users and to increase the probability of meeting management objectives.

Because random events appear to play an important role in determining cavity tree abundance, stand characteristics such as age, d.b.h., and density, and topographical features such as slope position and aspect cannot be used to accurately predict cavity tree abundance. Careful evaluation of habitat and monitoring of the populations will be necessary for effective management.

It is difficult to evaluate the abundance of cavities per se without more information on the relationships among snags, trees having cavities, and the populations of users. The abundance of snags was more than adequate according to Evans and Conner (1979), but the abundance of woodpecker cavity trees and woodpeckers was well below their recommendations for fair to good populations. Conner (1979) suggested that it would not be prudent to base management on minimums and that

management should attempt to provide habitat quality close to, but slightly below, optimum levels. It would seem that Middle Mountain would be considered as marginally ensuring viable populations of cavity-using birds. But there is no way to tell if snags were too few to support higher numbers of birds, if bird populations were too low to use the snags available, or if the management recommendations are overly conservative. It may be that "snag" (defined as a dead or partly dead tree) is not a useful management concept, or that 40 snags per pair of woodpeckers is too low a ratio for the purposes of habitat evaluation and management. The abundance of gray squirrel cavity trees was more than adequate according to Sanderson's (1975) recommendations.

Formation of Cavities

A major proportion of trees with cavities had diameters that were greater than 75 percent of the trees more than 10-cm d.b.h.; a significant number of these trees seemed to have been carried over from the previous harvested stand. A rotation age of 85 years is considered to be the maximum age for "good" oak sawlog management; 95 years is fair; 115 years is poor (Trimble et al. 1974). With an 85-year rotation, it may be necessary to leave clumps of trees to ensure future supplies of large cavity trees. The clumps should contain live trees vigorous enough to survive a second rotation, or trees sufficiently large to have developed top rot or to be suitable for techniques that accelerate cavity formation. Sanderson (1975) and Zeedyk and Evans (1975) provided guidelines for retention of such trees. Not only would carried-over trees provide large cavity trees in the subsequent mature stand, they would also facilitate the formation of cavities in the subsequent stand by permitting populations of gray squirrels and woodpeckers to become established earlier than would otherwise be possible.

A significant proportion of cavity trees were also in suppressed small trees. Although non-commercial intermediate treatments are not justified economically (Webster and Meadows 1974) or silviculturally (Carvell 1971, Kirkham and Carvell 1980, Smith 1962, Trimble 1971), demand for firewood has made intermediate cutting practical, bringing timber management into conflict with providing habitat for wildlife (Carey and Gill 1980). Firewood sales (or increased future demand for pulpwood or small roundwood) not only provide revenues and products but also improve sawlog yields (Gingrich 1971). Thus, although killing small trees for stand improvement and to ensure a continuous supply of dead trees for foraging and excavating cavities (Evans 1978) seems reasonable, such direct habitat improvement may not be economically feasible. But, commercial intermediate cuttings may become more frequent than in the past.

Ensuring viable populations of some cavity-nesting wildlife in the future may result in more opportunity costs than occurred in the past. Because 82 percent of the area in forests managed on an 80-year rotation are 40-60 years old (Roach 1974), it is unlikely that firewood demand will be great enough to prompt intermediate cuttings in all these stands. Much of the area occupied by these stands will be too far from roads or in topographic positions too unattractive to attract firewood cutters. But only 14 percent of the forest area would be 60-80 years old, and the scarcity of the older age classes would be more limiting than the abundance of small, dead trees in unthinned young stands. Extending rotations or retaining clumps of mature trees during harvests will be costly.

Kinds of Cavities

A diverse array of cavities and a good mix of bird and mammal cavities were found on Middle Mountain. Conspicuously scarce were trees with pileated woodpecker nest cavities and trees with large cavities. The sites on Middle Mountain were all upland sites. I have observed greater abundances of trees with large cavities and pileated woodpecker cavities on lowland sites and riparian areas where trees do not seem as susceptible to windthrow as on ridges or mountain sides. While I did not study lowland sites in the studies reported herein, the reduction in forests on lowland sites (Zeedyk and Evans 1975) may cause serious problems in ensuring supplies of large cavities and trees suitable for cavity excavation by pileated woodpeckers. Trends in land use and the patterns of abundance of this resource need more study.

Maple-Beech-Birch Forest

Most of the management implications of abundance of trees with cavities and formation of cavities in trees for the oak-hickory forest also apply to the maple-beech-birch forest. In addition, small, dead trees seemed to be of greater importance in the maple-beech-birch forest than in the oak-hickory. Recommended rotations for sawlogs are shorter (60-70 years) than in the oak-hickory (Trimble et al. 1974). Because site index is substantially higher in the maple-beech-birch than in the oak-hickory, intermediate cuttings may be economically justifiable (Webster and Meadows 1974), and timber management guides recommend thinning to reduce the loss of wood products to decay (Trimble 1963, Leak et al. 1969). But Roach (1977) felt that there was insufficient evidence to justify thinning to promote growth.

A less diverse array of cavities was found in the maple-beech-birch forest than in the oak-hickory forest. And the proportion of these cavities used by birds was lower than in the oak-hickory forest. More specific management would have to be undertaken in the

maple-beech-birch forest to ensure a supply of bird-cavity trees than in the oak-hickory forest. In particular, killing medium to large trees may be appropriate. Further research on, or careful monitoring of, the supply of cavity trees and the abundance of cavity-using birds should be undertaken.

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A Device for Viewing and Filming the Contents of Tree Cavities¹

Dan W. Speake² and James A. Altiere³

Abstract.--A miniature television camera system was tested for inspecting and video tape recording the contents of tree cavities and other animal dens. The camera is enclosed in a stainless steel cylinder 32 mm in diameter and 340 mm long and is connected to a flexible cable 38 m long. A lighted viewing accessory that has a fixed right-angle mirror is especially valuable for tree cavity work. The image is produced on a small television monitor component of the remote control camera unit, which is powered by a portable generator.

INTRODUCTION

It is well known that cavities in trees provide nesting and den sites for a wide variety of vertebrates, especially hole-nesting birds (Bull et al. 1980, Conner et al. 1975, Cunningham et al. 1980, Dennis 1971, Gysel 1961, Pinkowski 1976, Scott et al. 1977). Techniques used in the past to examine cavities include climbing the tree or snag and using flashlights and mirrors (Bellrose 1964, Gysel 1961, Seidensticker and Kilham 1968). Although these techniques are useful, each has limitations or dangers (Snyder and Rossol 1958). Improved methods for viewing the interior of tree cavities would have practical value for survey and research.

We recently acquired a "Miniature Underwater TV Camera for Nuclear Reactor Inspection ETV-1250," from Westinghouse Electric Corporation⁴. After a field demonstration by Westinghouse representatives, we determined immediately the utility of the camera for our current research needs, which required a method of inspecting the burrows of gopher tortoises (*Gopherus polyphemus*). After we had gained more experience and further tested the camera and accessory equipment, it became evident that the camera system would be useful for examining other relatively inaccessible places such as tree cavities.

We thank Larry Healy of Westinghouse Corporation for his invaluable technical guidance and

Terry Harper of the Auburn University Educational Television Department for advice and assistance with technical problems and the editing of video tape.

MATERIALS AND METHODS

The closed circuit TV camera system consists of two units: a camera head and a camera control unit connected with a 38-m flexible multilead underwater cable 14.5 mm in diameter (fig. 1). Several accessories are available for the camera head that permit axial and right-angle viewing, with or without an intergral light source. The camera head has a diameter of 32 mm and an overall length of 340 mm. One end of the camera housing is permanently attached and factory-molded to the cable. Threaded into the other end of the housing is the optical viewing port assembly, containing a quartz window. Both camera lighting and focusing are remotely operated from the camera control unit, which also has a 10.2-cm diagonal TV monitor. An external video outlet allows the use of a larger external TV monitor as well as a video tape recorder. The camera can operate at temperatures of -25° to 60° C. The special "Newvicon" tube provides increased light sensitivity, yielding a clear picture with low light intensity (0.015 foot-candle face plate illumination). For tree cavities, a lighted fixed right-angle lens is especially valuable because only the camera head needs be inserted into the cavity entrance. Little movement is required to view the entire cavity and its contents. A new lighted right-angle "fish eye lens" is being developed by Westinghouse that should facilitate the viewing of large cavities.

For field work a portable power supply is necessary. We have successfully used a portable electric generator that supplies 1,500 watts ac voltage, which is more than adequate to operate the camera and accessory equipment. Cavity contents are filmed with a Magnavox⁴ television video recorder that records on half-inch video tape. The use of an integrated switchbox enables instant review of recorded material in the field.

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²Dan W. Speake is Unit Leader at Alabama Cooperative Wildlife Research Unit, Auburn University, Ala.

³James A. Altiere is a wildlife technician at Alabama Cooperative Wildlife Research Unit, Auburn University, Ala.

⁴Reference to commercial products does not imply Government endorsement.



Figure 1.--Westinghouse Miniature Television Camera ETV-1250 control unit and camera with right angle-viewing attachment.

Camera and cable, control unit, generator and video equipment together weight 72.6 kg. The equipment can be transported with a four-wheel-drive vehicle, or (where that is not possible) with three-wheel all-terrain vehicles equipped with trailers.

We have used a light aluminum telescoping pole extendable to 4.3 m. The camera head is attached, with the cable hanging free. Cavities higher than 4.9 m have been approached with a light ladder. The ladder used in conjunction with the telescoping pole permits looking into cavities about 9 m above ground level. Methods for using the camera at heights considerably greater than 9 m are under investigation.

RESULTS AND DISCUSSION

We have examined numerous tortoise burrows and some 60 tree cavities (Table 1).

Using a lighted axial viewing "fish eye lens", we were able to clearly distinguish all occupants

of deep burrows with average diameters of about 30.5 cm. The camera can be focused on items as small as individual scales on snakes or small insects. A panoramic view of the burrow can also be obtained.

We tested camera resolution in the laboratory by attempting to distinguish both a coin (nickel) and small bird eggs at different cavity depths. By using the internal lighting system provided with the right-angle viewing attachment and inserting the camera head just inside the cavity opening, we could clearly distinguish these objects at distances up to 61 cm. With additional light, this distance could be extended much further. When the right-angle, "fish eye lens" becomes available, it may be possible, with adequate light, to view much larger hollows. Another especially valuable feature of the TV camera system is its capability for video-taping.

The two main limitations of the camera system now available are lighting for very large or deep cavities and the difficulty of reaching high cavities with minimum risk. It should be possible to reduce or remove both restrictions by further research and development.

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Table 1. Results of tree cavity¹ survey in which a miniature television camera was used as a viewing device.

Measurements (cm) of cavities				
DBH of trees (cm)	Height	Entrance diameter	Depth ²	Percentage of cavities active ³
$\bar{X}$	40	485	8.6	27.2
Ranges	(14 to 76)	(10 to 1219)	(4 to 51)	(0 to 76)

¹Includes 53 natural cavities in both live and dead trees and 7 bird boxes; all measurements are averages.

²Excludes hollow trees.

³Cavities occupied or with evidence, such as feathers or nesting material, of previous use.

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Monitoring Diurnal, Cavity-Using Bird Populations¹

ANDREW B. CAREY²

Abstract.--Monitoring cavity-using bird populations will be necessary to ultimately determine if habitat (snag) management is meeting the objectives set for management indicator species and helping to meet the major constraint of ensuring viable populations of all indigenous species of wildlife.

Recent advances in line-transect sampling theory, methodology, and data analysis suggested that not much additional effort is required to obtain a density estimate than is required to obtain a questionable index. Thus, to determine the applicability of line-transect sampling using measured distances to birds and Fourier series analysis of the decline in detectability, I developed a sampling protocol and surveyed diurnal, cavity-using bird populations in oak-hickory forests (98 km) and in beech-birch-maple forests (27 km) in West Virginia. Density estimates were obtained for two groups of species, primary and secondary cavity-users, in the oak-hickory forest. Coefficients of variation were reasonable for the groups, 12% and 14% respectively, and marginal for the estimates of density of most of the species (17-27%). Violations, and possible violations, of the assumptions were noted and are discussed; violations had more effect on the precision of the estimates than on the estimates themselves.

INTRODUCTION

My purpose in this paper is to address some limited aspects of the monitoring requirements now being addressed by the National Forest System (Salwasser et al. 1983). In particular, I deal with monitoring populations of cavity-using birds in upland deciduous forests in Appalachia. First, I reiterate the definition of monitoring. Then I discuss what should be monitored and formulation of objectives for cavity-using birds. Because of past reviews of sampling methods (Brewer 1978, Robbins 1978, Shields 1979), a recent symposium

addressing all aspects of estimating the numbers of terrestrial birds (Ralph and Scott 1981), and a clear, concise treatise of sampling design and statistical methods for biologists (Green 1979) I do not provide an extensive review of the literature. Rather I simply discuss the rationale I used in selecting the sampling and analytical methods to be used in my pilot study. Then I present an evaluation of the applicability of line-transect sampling using measured, perpendicular, horizontal distances and Fourier series analysis to measuring cavity-using bird populations. Finally, I make recommendations for monitoring.

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²When the work reported herein was done, Carey was research biologist, Northeastern Forest Experiment Station, USDA Forest Service, Morgantown, W.Va. Now, he is research coordinator, Old-Growth Forest Wildlife Habitats Program, USDA Forest Service, Olympia, Wash. 98502

Monitoring

Salwasser et al. (1983) defined monitoring as the "...collection and interpretation of population or habitat data, or both, to evaluate progress toward meeting objectives ...and indicate needed adjustments in... management...". They concluded that statistically reliable monitoring of populations (and

habitats) of wildlife and fish is a critical process in natural resources management.

Monitoring Requirements

The USDA Forest Service (1982:43048) requires that fish and wildlife habitat on National Forests be managed to maintain viable populations of native and desired non-native species, that management indicator species be chosen and their habitats be maintained or improved, and that population trends of management indicator species be monitored. In these requirements I perceive two different monitoring needs--one to monitor population trends, suggesting species- or group-specific indexes and the other to determine if population levels (densities and patterns of abundance) are sufficient to ensure that populations will persist through time. Undoubtedly, it can be assumed that without drastic changes in forest management practices or land use patterns the abundance of some species may obviate the need for monitoring. But other species seem more sensitive to the effects of management and current land use patterns. A group of species with these kinds of sensitivities is the cavity-using birds. Although our knowledge of cavity-using bird-habitat relationships is far from complete, there seems to be ample evidence for concern about maintaining viable populations of these species under intensive forest management, hence this symposium.

Objectives For Cavity-Using Birds

Determining what constitutes a minimum viable population is not an easy task. But Shaffer (1981) proposed a definition: "a minimum viable population for a given species in any given habitat is the smallest isolated population having a 99% chance of remaining extant for 1000 years despite the foreseeable effects of demographic, environmental, and genetic stochasticity, and natural catastrophe". Conner (1979) suggested that minimum standards for threatened and endangered species should be to provide habitat as close as possible to the optimum for the species. And that for other species, management to provide habitats between the mean optimum environment and one standard deviation below this mean should suffice. Evans and Conner (1979) suggested levels of abundance of snags and densities of woodpeckers that could correspond to a variety of objectives for cavity-using birds in northeastern deciduous forests. Thus it seems that objectives formulation has gone as is reasonable with our current knowledge and that it is now appropriate for monitoring to start "feeding back" information about objectives.

A SAMPLING PILOT STUDY

I began research on cavity-using wildlife in Appalachia in 1979. It was readily apparent that there was a lack of quantitative information on some fundamental aspects of the ecology of cavity-using wildlife. Little was known about the patterns of abundance of snags (dead or partly dead trees) and trees containing cavities. Likewise the relationships between snag and cavity-tree abundance and the abundance of cavity-using birds had not been quantified. And the numerical relationship between the primary cavity-excavators and secondary cavity-users had not been described. The natural variability of these abundances and relationships within and among biotopes was also unknown. All these items are key information for effective management. Therefore I initiated studies of the patterns of abundance of cavity-trees (Carey and Healy 1981, Carey 1983). But it was apparent that sampling techniques for quantifying the abundance of cavity-using birds were just being developed. Therefore I began pilot studies to determine if population densities could be precisely estimated.

Choosing A Technique

I decided that sampling techniques that provide relative abundance (indexes to actual abundance) would be inadequate for quantifying the relationships I was interested in and for subsequent monitoring for several reasons. First, indexes (numbers per unit effort, such as birds/time spent listening, birds/distance walked, birds/area searched) are not very useful unless calibrated by actual density estimates and therefore lack the basic qualities required for making inferences about many parameters (White et al. 1982). Second, indexes do not permit comparisons among species (for example, species A is more abundant than species B). And within species comparisons may be substantially biased by differences just in detectability of species in differently structured environments or by different observers (Shields 1979, Ralph and Scott 1981). Indexes, when rigidly standardized (sampling must be conducted in the same season, time of day, weather, and habitat), can be used to qualitatively monitor local population changes of a single species from year to year. Conner and Dickson (1980) suggested that relative abundances derived from strip transects could be used to evaluate the effects of silvicultural (or other) treatments on birds communities. It seems to me that if sufficient effort is expended to adequately sample bird populations to obtain reliable indexes, the additional effort required to model the decline in detectability of the birds from the transect line in order to estimate densities would not be great compared to the gain in the reliability and comprehensiveness of the

information and in the confidence that could be placed in the results. In addition, I feel that there are many often unstated or unexamined assumptions required for indexes that are unwarranted. For example, the assumption that the relationship between the index and the actual density does not change with density or with species composition of the community being sampled may not be warranted. Finally, I feel that there is a tendency among biologists to be less careful when collecting data for indexes than when collecting data for density estimates because they are "just after an index, not density".

All methods for estimating bird abundance require assumptions and incorporate some bias, inaccuracy, and imprecision. Therefore, in deciding on a method to use, I considered criteria such as applicability for sampling large or numerous areas and criteria that assumptions should be minimal, that standardization of the procedures to reduce bias should be practical, and that analytical procedures should be robust to violations of assumptions. I rejected the spot (territory) mapping technique because it is not easily applied to sampling large areas (Robbins 1978). Variable circular plots, line-transects, and other types of transect methods are appropriate for extensive sampling (Scott et al. 1981). I decided not to use the variable circular plot methods (Reynolds et al. 1980) because it seemed to me that too much effort would be expended in getting from plot to plot in roadless areas at the expense of collecting data. And because I would be sampling when trees were leafless and visibility would be good, the major advantage of the method--that of detecting birds in dense forests where visibility is low--was not important. Some informal field testing indicated that fewer cavity-using birds were seen per effort expended using variable circular plots. And many of the birds were first detected when their movement into the area caught the eye of the observer. Movement into the area being sampled violates major assumptions of any analytical method used to calculate density estimates from variable circular plot data. Line-transects attempt to reduce the effects of bird movement by having observers move at a rate that is fast relative to the movement of the birds. Therefore I decided to use a transect method.

Two categories of transect methods, strip-transects and line-transects, are applicable to estimating bird densities. Strip-transects entail recording all birds detected (seen and/or heard) out to a prescribed distance from the transect line whereas line-transects do not have boundaries (Eberhardt 1978). In the simplest case, when one can assume that all the birds present in a strip were detected, density estimates are straightforward; Amman and Baldwin (1960) estimated woodpecker densities in coniferous forests with

this approach. However, in most situations one cannot assume all the birds present were detected and prescribing a narrow strip results in small sample sizes and in ignoring detectable birds. Detectability usually declines with increasing distance from the transect line. The decline in detectability must then be modeled before density estimates can be made. Emlen (1971, 1977) and Jarvinen and Vaisanen (1975, 1976) proposed approaches to modeling the decline in detectability that have been widely accepted. Dickson (1979) used a variation of Emlen's (1971) method to estimate cavity-using bird densities in Louisiana. However, these approaches rely on unwarranted assumptions and are subject to a variety of biases and errors (Shields 1979). Unwarranted assumptions include assumptions about the shape of the detectability function and the assumption that predetermined strip widths are optimal for all species. Biases arise from differences among observers in ability to estimate distances ocularly and aurally. In order to overcome some of the inherent biases and arbitrariness in transect methods, Burnham et al. (1980) suggested using line-transects with a nonparametric approach (Fourier series analysis) to modeling the decline in detectability. The perpendicular distance from the transect line to each bird detected is recorded. Careless or inaccurate measurements and rounding errors can lead to poor estimates of density and sampling variances, therefore distances should be measured, not ocularly or aurally estimated (Anderson et al. 1979). The perpendicular distance can also be calculated from the sighting distance and sighting angle if the bird is observed forward of the observer and the distance and angle are measured. Measuring the sighting angle and distance ensures a perpendicular distance even if the observer can no longer see the bird when he moves up the line. However, errors in sighting angle and distance are compounded in the calculated perpendicular distance. In addition, I feel that perpendicular distances must also be horizontal distances to obtain accurate density estimates. In rugged topography it is often hard to measure horizontal distances directly. Therefore the angle of departure from the horizontal should be measured and used to correct non-horizontal perpendicular distances.

There are many factors in addition to measurement errors which contribute bias and cause errors in transect-derived density estimates (Anderson et al. 1979, Shields 1979). Factors which affect an observer's ability to detect birds include the speed at which the line is walked, the observer's physical ability (to hear, to see, to avoid fatigue), topography, weather, and the structure of the forest vegetation. Interspecific differences (size, coloration, and behavior), intraspecific differences (particularly those due to age and gender), seasonal-, diel-, and weather-related behavioral changes, and

responses to competitors and predators determine the conspicuousness of the birds. The effects of these factors can be ameliorated through standardization of procedures, training sessions for observers, confining the sampling to a short time period within a biologically defined season, confining the sampling to morning hours, not sampling on windy or rainy days, and use of robust statistical analyses. Thus, I decided to use line-transect sampling with measured angles and distances and to record birds as within or outside of a 25-m boundary so that the Finnish line-transect method (Jarvinen and Vaisanen 1975) could be used should too few measured perpendicular distances be obtained.

Study Areas

My initial study area was in the oak-hickory forest on Middle Mountain in Greenbrier and Pocahontas Counties, West Virginia. Later, study areas were chosen from maple-beech-birch stands in Randolph and Tucker Counties, West Virginia. Both study areas were described elsewhere in this symposium (Carey 1983). Gill et al. (1975) established 57 parallel transects across Middle Mountain. They randomly located the initial transect and established subsequent transects at 0.4-km intervals from the initial transect. The beginning of each transect was randomly located within 40 m of the southeastern Forest Service boundary. Permanent metal markers were placed every 80.5 m along each transect until the northwestern boundary was reached. I used the center four transects (numbered 26-29). I placed transects along the long axis of one 206 years old, two 100 years old, and three 65 years old maple-beech-birch stands.

Sampling Procedures

Three experienced biologists (J. D. Gill, W. M. Healy, and me), interested in the study and familiar with the local avifauna, were the observers. Each biologist had detailed, written instructions (modified from Anderson et al. 1979 and Shields 1979), a hand-held compass for measuring angles, a short-distance (2 to 30 m) optical rangefinder, a long-distance (15 to 180 m) optical rangefinder, binoculars, pencils, and data forms. The instructions were designed to reduce observer variability and specified (1) start shortly after sunrise, (2) walk at an average speed of 1 km/hour (4 min. between transect-line stakes), (3) scan from side-to-side but pay particular attention to the areas nearest the line to avoid missing birds on the line (a major assumption of line-transect analysis is that all birds on the line were detected), (4) record the average of at least 2 measurements for each variable (sighting angle, sighting distance, perpendicular distance, angle of departure from the horizontal), and

(5) if a bird cannot be seen, record it as ≤ 25 m or > 25 m from the line. The angle of departure of the line of sight from the horizontal was included to allow the perpendicular distance to be corrected to horizontal perpendicular distance when a horizontal perpendicular distance could not be directly measured (e.g., a bird in a tree top, or below in a lower topographical position).

In addition, each biologist was instructed to record any observations that indicated violation of the assumptions of line-transect sampling. Specifically, records of bird moving at first detection, birds fleeing or being attracted to the observers, birds evading, moving in front of or along with the observers, and problems in distance measurement were to be made. These observations were discussed and summarized each day.

Two 1-km transect lines with targets at measured distances (24 targets, 1.3 to 57.0 m from the line) were used to train the biologists in procedures and to increase their proficiency with the rangefinders.

Each of the four Middle Mountain transects (26 to 29) was subdivided into three consecutive (end to end) 1-km lines separated by 40 to 120 m (fig. 1). Each set of three lines were separated by 0.4 km. Thus, total transect length was 12 km. The lines were well marked with flagging and paint, and the permanent stakes were renumbered. The transects were perpendicular to the main ridge of Middle Mountain; thus the lines were along elevational gradients. None of the lines was on a trail or along another discontinuity such as a stream. Similar procedures were followed in establishing the maple-beech-birch transects, except lines were generally along contours. Transect lengths were 0.8-2.0 km.

Bird surveys were conducted in winter (8 to 13 December 1980) in the oak-hickory and in spring in the oak-hickory (1 to 9 April 1981) and in the maple-beech-birch (26 April-2 May 1982). Winter is a long period of relatively constant bird behavior and good visibility (deciduous trees are leafless) and thus offered the potential for long sampling periods. Spring samples were taken during the breeding season of cavity-nesting birds, a time when the birds are most conspicuous and most stationary. Because cavity-nesting birds breed earlier (February-April) than most other birds, the trees were still leafless and visibility was good.

In the winter survey each biologist was assigned one set of three 1-km lines by random drawing. The rate of traverse (1 km/hour) proved to be too fast for winter conditions in the rugged topography. Thus, only two 1-km lines were surveyed each day (at 0.5 km/hour) by each biologist; 36 km were surveyed. Because

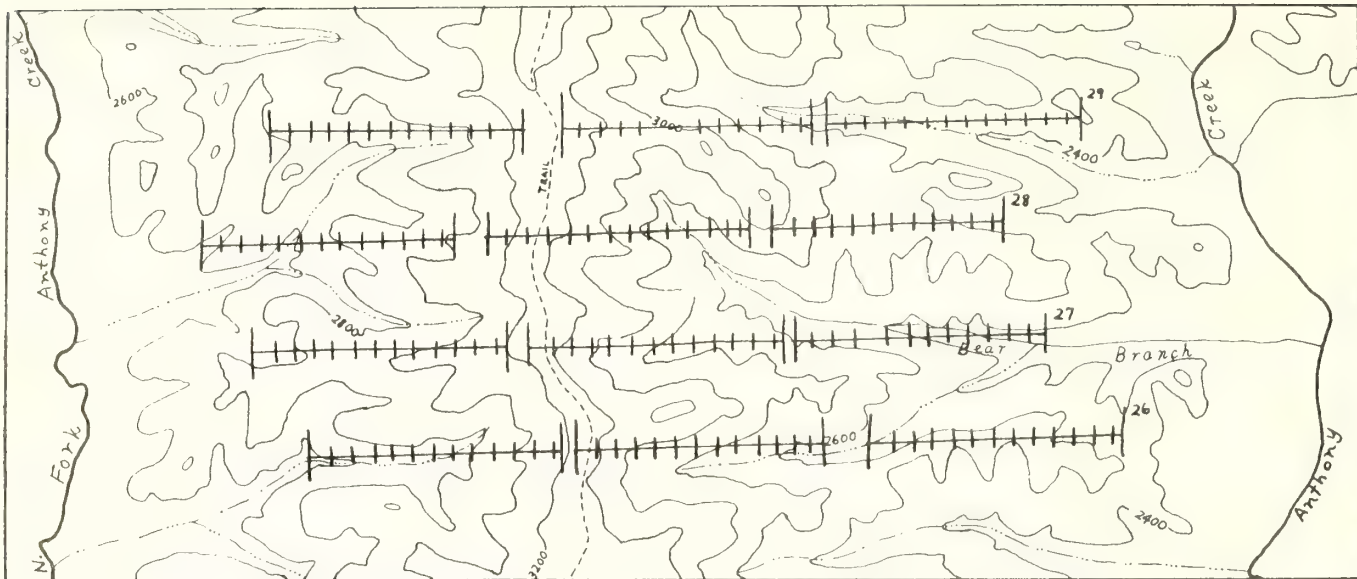


Figure 1. Middle Mountain line transects; each transect is 1-km with stations at 80.3 m.

surveying the same lines day after day proved to be too boring to allow proper concentration, a rotating sequence using all four transects was used in the spring, with the starting transects randomly assigned. A speed of 1 km/hour and a sample of three 1-km lines per biologist per day proved possible in the spring; 62 km were surveyed.

Analytical Procedures

The computer program TRANSECT (Laake et al. 1979) and the Fourier series analysis were used to analyze the measured distances data. This method is pooling robust (Burnham et al. 1980:45), not sensitive to differences among observers, biotopes, and species. Thus, the observations recorded by the biologists were pooled for two groups, cavity-excavating species and secondary (non-excavating) cavity-users. When the number of distances measured was large, species population densities were also estimated.

The data consisting of all cavity-using birds seen or heard were analyzed for a 20-m fixed width strip (10 m on either side of the line), a 50-m fixed width strip (25 m on either side of the line), and the improved Finnish method (Jarvinen and Vaisanen 1975) with birds recorded as within or more than 25 m from the line. Fixed width strip analyses assumed that all birds in the strip were seen or heard. The improved Finnish method of analysis assumed a linear decline in detectability with one parameter estimated. That parameter was k , the species specific constant for detectability, where $k = (1 - \sqrt{1-p})/W$. W was 25 m and p was estimated by dividing the number of birds detected within 25 m by the total number detected. The equation

used to calculate density was: density (birds per km^2) = $1000N K/T$, where N is the total number of birds detected, and T is the number of kilometers of transect surveyed.

Results

Winter Survey

It was not possible to obtain density estimates from the winter survey data. Of 232 cavity-using birds recorded (seen or heard) during 36 km of surveys, 126 (54%) were in 28 feeding flocks (Table 1). Most of these flocks were moving rapidly and it was not possible to obtain accurate counts of flock members. Nor was it feasible to determine the flock center. Thus, the flock data were not suitable for density estimation (Burnham et al. 1980:31). The median perpendicular distance at which the leading edges of the flocks were detected was 11.0 m. The average species composition of flocks was 2.67 black-capped chickadees (*Parus atricapillus*), 1.86 golden-crowned kinglets (*Regulus satrapa*), 1.29 white-breasted nuthatches (*Sitta carolinensis*), 0.25 tufted titmice (*P. bicolor*), 0.25 red-breasted nuthatches (*S. canadensis*), 0.21 brown creepers (*Certhia familiaris*), 0.21 downy woodpeckers (*Picoides pubescens*), and 0.18 hairy woodpeckers (*P. villosus*). Perpendicular distances were measured to 34 stationary birds that were not in flocks (Table 1); 56 other birds were heard but could not be precisely located; 16 were seen while they were moving. Some birds flew in to investigate the observers; others fled at the approach of the observers. Birds could be detected from great distances. For example, pileated woodpeckers (*Dryocopus pileatus*) were heard at distances of 320 to

Table 1. Number of cavity-using birds recorded and detection distances measured during a winter survey of 36 km of line transects on Middle Mountain in West Virginia in 1980.

Species	Total	In a flock	Not in a flock			
			<25m	>25m	Median distances	
					N	M
Pileated woodpecker	23	0	0	17(6) ¹	6	71
Hairy woodpecker	40	5	23(11)	12(4)	15	19
Downy woodpecker	22	6	12(7)	4(2)	9	9
White-breasted nuthatch	54	36	9(4)	9(0)	4	8
Red-breasted nuthatch	7	7	0(0)	0(0)	0	-
Tufted titmouse	7	7	0(0)	0(0)	0	-
Black-capped chickadee	79	75	0(0)	4(0)	0	-
Total	232	136	44(22)	46(12)	34	19

¹Total number detected, including those to which distance was only estimated as within or beyond 25 m, and in parentheses number to which distance was measured; birds moving before they were detected are not included.

1,000 m and hairy woodpeckers were heard at distances of >240 m (distance estimates are based on actual sighting or on stationary birds near the transect lines that could be heard well forward of the observer). Despite general differences between calls and drumming among species of *Picoides* woodpeckers, it was not possible to identify some individuals positively from calls or drums. In addition, species in flocks shared a "feeding" call.

Spring Survey, Oak-Hickory Forest

Breeding activity, as evidenced by singing, drumming, chasing, courting, defending territories, mating, and excavating cavities, was underway during the spring survey. However, some black-capped chickadees were in small feeding flocks with golden-crowned kinglets, and some downy woodpeckers were foraging near white-breasted nuthatches. Birds were often conspicuous at great distances, but some, such as hairy woodpeckers, were easily alarmed and would hide or give alarm calls at the approach of an observer. Pileated woodpeckers and common flickers (*Colaptes auratus*) seemed particularly evasive; both species were observed moving ahead of observers. Stationary pileated woodpeckers were hard to locate because they would stay near the base of a tree or move to the ground to give alarm calls.

More cavity-users were recorded in the spring (N = 388) than in the winter (N = 232); in part because the number of kilometers walked was greater in the spring (62 km versus 36 km). Also yellow-bellied sapsuckers were present in the spring but not in the winter. Likewise, more distances were measured in the spring (N = 144) than in the winter (N = 34), (Tables 1 and 2). Although common flickers and a red-bellied woodpecker (*Melanerpes carolinus*) were present on the study area, none were detected before or at flight on the lines and no distances to these species were measured. Densities estimates were made using ungrouped distances (Table 3) and distances grouped into 10-m intervals extending laterally from the lines (Table 4). Program TRANSECT indicated that 10 m was the optimum grouping interval. Grouping (Table 5) reduced the coefficients of variation (CV) substantially, probably because there was "heaping" in the data (Burnham et al. 1980:48). Heaping refers to clustering of distance values as opposed to a continuous distribution of values. The CV's for the density of primary (12.4%) and secondary cavity-users (13.9%) were reasonable but those for individual species were somewhat high (16.6 to 27.4%). Lowering the CV to 10% would have required surveying 120 km for secondary, and 107 km for primary, cavity-users. A CV of 20% could have been obtained by surveying 30 km for secondary, and 24 km for primary cavity-users. Thus one observer would require

Table 2. Numbers of cavity-using birds recorded and detection distances measured during a spring survey of 62 km of line-transects on Middle Mountain in West Virginia in 1981.

Species	Total	Detection distance			
		<25 m	>25 m	Median	
				N	M
Pileated woodpecker	61	4(3) ¹	57(2)	5	22
Red-bellied woodpecker	6	0(0)	6(0)	0	25
Common flicker	3	1(0)	2(0)	0	25
Hairy woodpecker	37	20(16)	17(6)	22	13
Downy woodpecker	38	16(14)	22(7)	21	13
Yellow-bellied sapsucker	30	26(24)	4(4)	28	10
White-breasted nuthatch	69	18(16)	51(1) ²	17	11
Red-breasted nuthatch	2	2(2)	0(0)	2	0
Tufted titmouse	28	3(3)	25(0)	3	7
Black-capped chickadee	114	73(44)	41(2)	46	7
Total	388	163(122)	225(22)	150	9

¹Total number detected, including those to which distance was only estimated as within or beyond 25 m, and in parentheses number to which distance was measured.

²White-breasted nuthatches were vociferous and their calls often were heard at distances from which the birds could not be seen.

Table 3. Densities of cavity-using birds calculated from ungrouped perpendicular distances from transect lines by using Fourier Series analysis; data from spring 1981, 62-km survey on Middle Mountain in West Virginia.

Statistic	Cavity-using birds	
	Primary ¹	Secondary ²
Perpendicular distance		
N	76	68
x	17.29	10.42
SE	1.60	0.98
Density per hectare		
N	0.249	0.335
SE	0.048	0.047
CV, %	19.1	14.2
CI, 95%	0.155-0.342	0.242-0.428

¹Includes pileated, hairy, and downy woodpeckers, and yellow-bellied sapsuckers.

²Includes black-capped chickadees, white-breasted nuthatches, red-breasted nuthatches, and tufted titmice.

Table 4. Densities of cavity-using birds calculated from perpendicular distance frequencies grouped in 10-m intervals laterally from transect line by Fourier series analysis; data from the spring 1981, 62-km survey on Middle Mountain in West Virginia.

Species	N	N/ha	SE	CI, 95%	CV, %
Primary cavity-users ¹	76	0.196	0.024	0.149-0.244	12.4
Hairy woodpecker	22	0.054	0.013	0.028-0.079	24.2
Downy woodpecker	21	0.055	0.015	0.025-0.084	27.4
Yellow-bellied sapsucker	28	0.086	0.017	0.052-0.121	20.6
Secondary cavity-users ²	68	0.406	0.056	0.295-0.517	13.9
Black-capped chickadee	46	0.265	0.044	0.179-0.351	16.6

¹Includes pileated, hairy, and downy woodpeckers and yellow-bellied sapsuckers.

²Includes black-capped chickadees, white-breasted nuthatches, red-breasted nuthatches, and tufted titmice.

Table 5. Frequencies of distance measurements by 10-m intervals; data are from the spring 1981, 62-km survey on Middle Mountain in West Virginia.

Species	Perpendicular distance in meters					
	0-10	11-20	21-30	31-40	41-50	51-60
Primary cavity-users	32	17	13	8	4	2
Hairy woodpeckers	8	7	3	1	2	1
Downy woodpeckers	9	3	3	5	1	
Yellow-bellied sapsuckers	14	5	6	2	1	
Secondary cavity-user	42	22	2	1	1	
Black-capped chickadee	29	14	2	1		

8 to 10 good weather days (surveying 3 km/day) to obtain point estimates with CV of 20%.

Spring Survey, Maple-beech-birch Forest

A total of 21.6 km were surveyed; 6 km in the 206 years old stand, 6.5 km in 100 years old stands, and 9.1 km in 65 years old stands. Only 25 distance measurements were made. Similarly, few birds were heard. As the rate of observations was 1.1 measurements/km and was one-half the rate recorded in the oak-hickory it was apparent that we would not obtain a sufficient sample size in the time that had been allotted for sampling; therefore sampling was discontinued. The weather during sampling was warm and partly cloudy to clear.

Discussion

Sampling Assumptions

The reliability of density estimates by line-transect rests on five assumptions (Burnham et al. 1980:14):

Birds Directly On The Line Are Never Missed:--I believe this assumption was met. Concentrating searching on the line and the leafless trees made it unlikely that birds on the line were missed. It is important to note that this assumption applies to the line itself, not to the entire sampling area surrounding the line. It is not required, nor is it likely, that all the birds near the line are detected.

Birds Do Not Move Before Being Detected:--Movement by birds does not have a detrimental effect unless the movement is in response to the observer and before the bird is detected. This assumption was violated in at least a small proportion of the potential occurrences. Pileated woodpeckers and common flickers actively evaded the observers by moving from or along the line. However, a more typical response was an alarm call or evasive behavior without substantial distance movement; for example, moving around a tree. Birds often did flee when the observer came near, but then they were most often detected at or before flight.

No Bird Is Counted More Than Once:--The potential for an individual observer to count the same bird more than once was low, except for pileated woodpeckers and common flickers.

However, when the observers were simultaneously traversing parallel transects on Middle Mountain, the potential for double counting increased, even with the transects 0.4 km apart. On at least one occasion, pileated woodpeckers fleeing one observer landed near another observer 0.4 km away.

No Measurement Or Rounding Errors Occur:--

This assumption was violated. Although rangefinders were calibrated daily and the observers were experienced, measurement errors probably occurred. Jiggling or bumping the rangefinders could change this calibration. It could also be affected by trying to measure distances outside the range of the rangefinders. Lighting conditions affected the observers' ability to make measurements. Hand-held compasses are crude devices for measuring sighting angles and angles of departure from the horizontal. Heaping was noted in the data, suggesting rounding errors. I assumed that there was no systematic bias, only random error, in the distance measurements. Comparison of detectability histograms of perpendicular distances corrected to horizontal perpendicular distances with histograms of uncorrected perpendicular distances revealed that if distances had not been corrected there would have been a tendency for more birds to be recorded at intermediate distances than close to the line. Thus, failure to record horizontal distances would have resulted in overestimates of bird densities.

Sightings Are Independent Events:--Lack of independence does not affect the point estimates of density but does affect the estimates of variance. This assumption was violated when birds were in flocks or pairs. Thus, the greatest bias was in the variance of black-capped chickadee density. In addition, stopping to locate a visually inconspicuous bird often resulted in additional birds being detected.

Methodology

The violations of assumptions were not as severe as can be expected when distances are visually estimated or when aural cues are used to estimate distances. In future studies, biases could be further minimized by strictly adhering to sampling protocols (e.g., keeping pauses brief), wearing camouflage clothing (safety colors were worn early in this study), not using aluminum (reflective) clipboards, using clinometers to measure the angle of departure from the horizontal, and taking extreme care in using the rangefinders.

Rate of traverse is an important variable that needs to be optimized, but it is hard to standardize. There are tradeoffs among detecting birds, avoiding the bias of bird movement (i.e., the rate of traverse should be fast relative to the movement of the birds), sampling sufficient areas, and remaining inconspicuous to the birds. Speed must be

adapted to the difficulty of traverse and is necessarily slow when birds are present and measurements must be made. It was the consensus of the biologists in the study that subjective judgement is necessary. An analogy with still-hunting can be made--walking at a careful, slow rate (adapted to footing and terrain) with numerous brief pauses and, once a target is detected, assuming a stalking mode until all measurements are ensured. Such a speed would be variable, ranging between 0.5 km/hour and 2.0 km/hour in rugged terrain and averaging 1.0 km/hour.

Accuracy and Precision

There is no way to judge the accuracy of the density estimates because the actual densities were unknown. But the line-transect/Fourier series analysis can be compared to other methods. Total cavity-using bird density calculated from all birds seen or heard within 10 m of the transect line was (assuming all present were detected) 0.597 birds/ha. Density calculated by the improved Finnish method was 0.604 birds/ha. These estimates are strikingly close to those derived by Fourier series analysis (0.602/ha). But density estimated from all birds seen or heard within 25 m of the line (assuming all present were detected) was 0.526 bird/ha and 13% lower than the other estimates, indicating detectability had declined significantly.

Likewise it is hard to evaluate the precision of the estimates as many authors fail to report actual sample sizes, let alone variance estimates. But Tilghman and Rusch (1981) did report coefficients of variation of line-transect density estimates calculated by 12 methods of analysis (but not Fourier series analyses). Distances were aurally or visually estimated and evidently not corrected to horizontal distances. Coefficients of variation for black-capped chickadees for 11 of the 12 CV's for black-capped chickadee density were greater than 35%; one was 19.1%. The CV for black-capped chickadee density on Middle Mountain was 16.6%. Average (over 12 methods) CV's for nine species were 32.6-56.1%; on Middle Mountain, CV's were 16.6-27.4%. Scott et al. (1981) reported that 10% error in distance estimation would result in 20% error in density estimates. I would expect that my CV's would have been lower yet if a more homogeneous environment had been sampled; 35 stands were intersected by the transects which encompassed two major aspects and 300 m elevation. In addition, some variability had to be introduced by multiple observers and measurement error, especially in angles, that could have been reduced by using clinometers or better rangefinders.

Density Estimates

There are few reliable estimates of cavity-user abundance in northeastern hardwood forests. I believe the ones reported here are more reliable than most. Evans and Conner (1979) used percentages of maximum densities of woodpeckers to set management goals: 80 to 100% for "good", 40 to 60% for "fair", and 20% of the maximum for "poor" environments. Maximum densities were calculated from territory sizes. Using their criteria, Middle Mountain would be rated a poor environment for hairy and downy woodpeckers (11% and 22% of maximum densities) and an excellent environment for yellow-bellied sapsuckers (172% of the maximum density). The yellow-bellied sapsucker was the only migratory species for which distances were measured; it may be that some of the sapsuckers observed were still migrating. Combining maximum densities for the woodpecker species included in my density estimates indicated a poor environment overall (24% of maximum). My subjective evaluation of Middle Mountain, based on other studies (Carey and Healy 1981; Carey, 1983), is that it is at least a fair, and probably a good environment for cavity-using birds. The stands on Middle Mountain had not been subjected to intensive management (e.g., thinnings or improvement cuttings) but had been damaged by ice storms; 50% of the trees had evidence of butt- or top-rot and 10% had one or more large (>8 cm) dead branches. The stand ages and condition of the trees suggest that the potential for cavity-formation was high (Carey and Sanderson 1981). Snag densities were much higher than recommended by Evans and Conner (1979) but the abundance of woodpecker cavity-trees was well below their recommendations for fair-good populations (Carey 1983).

The maple-beech-birch forest had even lower abundances of birds and woodpecker cavity-trees. I spent a considerable amount of time over a three-year period in the study areas (Carey and Healy 1981, Carey 1983) and I and my co-workers were quite struck by the paucity of cavity-using birds compared to the oak-hickory forest. As I previously noted (Carey 1983) there was a distinct lack of stands older than 60-70 years in our two-county study area.

RECOMMENDATIONS FOR MONITORING

Management indicator species such as pileated woodpeckers are not easily studied by the techniques I presented here. Therefore I will confine my recommendations to the more general aspects of sampling cavity-using bird communities composed of hairy woodpeckers, downy woodpeckers, yellow-bellied sapsuckers, and the secondary cavity-using birds. I do this because my knowledge and experience in sampling bird populations rests with the latter, not because I wish to down play the former. The

pileated woodpecker plays a major role in the formation of cavities for most-cavity-using wildlife (Carey 1983) and its ecological requirements are such that it probably is more sensitive, in the short-term, to intensive timber management than the other cavity-using birds.

The time is approaching when increased harvest of trees in eastern deciduous forests may be stimulated by the maturing of second- and third-growth stands, demand for wood as fuel (Carey and Gill 1980), attempts to create new markets through forest products research and research on harvesting methods, and the projected wood shortage that always seems to loom just over the horizon. Future harvests will not leave the residual trees (cull trees and undesirable timber species) that were left in the past and that ameliorated the effects of past harvests on cavity-using wildlife (Carey 1983). And intermediate cuttings have become economically feasible, and thus more frequent (Carey and Gill 1980). The changes that could occur in cavity-using bird populations and community composition because of changes in the proportions of the stages of forest development could be considerable (Kendeigh 1982). If the decision is made by forest planners to monitor cavity-using bird populations because of concern over the impact of intensive timber management on the environment's capability to maintain viable populations of cavity-dependent species, biologists may be hard-pressed to respond if baseline data are lacking. There have been few long-term baseline studies. Kendeigh (1982) conducted such a study. His principal finding was that "avifauna is in continual flux correlated with time and space...populations fluctuate in yearly cycles, from year to year, and less conspicuously over decades and longer intervals...variations occur intra-regionally in species composition and population sizes...changes in community structure accompany these fluctuations and variations." Factors contributing to fluctuations were numerous and included changes in vegetation (proportions in various stages of forest development) that influenced interspecific competition for territories, food, and nesting sites and thereby greatly influenced populations levels attained by cavity-using birds including the various species of woodpeckers, tufted titmice, and white-breasted nuthatches. Thus I recommend instituting baseline monitoring studies, not only to document the patterns of fluctuations in cavity-using bird abundance, but also to quantify the relationships among cavity-tree abundance, forest structure, abundances of cavity-excavators, and abundances of secondary cavity-users. As Kendeigh (1982) pointed out, species may vary locally in biotope requirements depending on the vegetation, interspecific competition, and prevailing climate.

If the decision is made to monitor cavity-using bird populations, several aspects of experimental design will be of importance because population monitoring is time consuming and expensive. Stratification by age class (or silvicultural treatment) and forest type will be necessary; I found considerable differences in abundance and types of cavities between the oak-hickory and maple-beech-birch forests. Within strata, stands to be sampled should be chosen randomly so that the results may be extrapolated to the planning unit; "grabbing a handful is not the same as random sampling" (Cochran et al. 1954). Controls would be desirable but difficult to choose; every stand changes with time and mature stands developed under management would surely be different from "natural" or unmanaged stands. Disease and insect attacks on trees can greatly influence the avifauna. In the absence of catastrophic events, wilderness or other reserved areas could serve some functions of control areas. Green (1979) provide a good review of sampling design.

Because of the dynamic nature of the forest environment, and because of the great variability in similarly treated stands (Carey 1983) I recommend that monitoring be in terms of population densities, not relative abundances. I recommend variable circular plots for small stands where one or two 1-km transect lines cannot be surveyed and line-transects for larger stands. With both procedures, I recommend recording both measured, horizontal, perpendicular distances and aural estimates. Measured distances can be used to determine the relationship between rigorous sampling techniques and less-demanding techniques in environments of various structure and composition. If good correspondence is found between, say, line-transects with measured distances and Fourier series analysis and improved Finnish line transects, then the only distances that would have to be measured would be those near 25 m. Measured distances, Fourier series analysis, and the improved Finnish method can be easily applied to variable circular plots. I recommend avoiding techniques that rely on visual and aural estimation of distances over a wide range of distances, for example, the variable width line-transects. I recommend double sampling and consideration of non-measured distances not because I found distance measurement cumbersome and time consuming (I didn't), but because if the relationship between techniques is well demonstrated, then aural cues could be used and would result in greater sample sizes and thus possibly would permit more stands to be sampled. If the decision is made to monitor all diurnal, forest bird populations, the distance measurements could not only become time consuming and cumbersome but also impractical because sampling would have to be delayed until the general breeding season when trees are in full leaf. However, I recommend that specific groups of

target species be chosen for monitoring so that observers can concentrate searching for them without being faced with having to detect, recognize, and estimate distances to all birds.

Finally, it is important to recognize that survey procedures and analytical methods will be improved. But in the interim, I recommend the guidelines proposed by Anderson et al. (1979), Shields (1979), and herein for sampling methodology and the critical examinations of assumptions and biases presented by Burnham et al (1980) and especially by the various authors in Ralph and Scott (1981).

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A Simple Model to Predict Snag Levels in Managed Forests¹

Norm Cimon²

Abstract.--The need for quantitative estimates of snag levels is discussed. A simple model to predict snag levels in managed forests is developed. Projections of standing snags in two diameter classes for a typical managed stand are developed. The model, once verified, may prove its usefulness when incorporated within existing stand simulations.

INTRODUCTION

Snags as Habitat

Snags are an essential component of the habitat requirement for many species of wildlife. In the Blue Mountains of Oregon, for example, it is known that upwards of 60 different birds and mammals are cavity users (Thomas 1979).

Current Snag Research

The importance of snags leads quite naturally to a series of questions: What type of snags are important? How many snags per acre, and of what species and diameter class, does it take to meet the specific requirements of a given species of bird or mammal? What role does forest succession play? Does the stage of decay of the snag have a significant impact on potential cavity users? I am certain that the reader could add many more to the list.

In fact, questions like these are the source of much of the active research in the field of snag management (Balda 1976, Conner 1973, Mannan 1977, McClelland 1975, Scott 1978). Many of these questions either have been or are in the process of being answered. To return to the case of the Blue Mountains,

Thomas (1979) detailed the specific requirements, by diameter and tree species, for each of the cavity using birds and mammals.

Need for a Predictive Model

It starts to become evident that what is needed is a model that would project snag levels over time for all relevant species and diameter classes. With such a model, and the species specific requirements mentioned above, the wildlife manager would have the tools at hand to protect required levels of wildlife by protecting the needed snag habitat.

The rudiments of such a model were originally described in a paper by Bull et al. (1980). In this paper, I have extended the 1980 model by developing separate equations for each diameter class, and by including provisions for the growth of live trees from one diameter class to the next. This model explicitly attempts to predict the number of snags available, for a given tree species per acre by diameter class, over a series of planning intervals.

METHODS

Requirements for the Model

In this simplified model, prediction involves knowledge of certain basic information at each stage of the planning process. First of all a planning interval must be selected. For the purposes of the example given below, the interval chosen was 10 years. This is to say that the model will be updated in 10 year increments.

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²Norm Cimon, 1207 Y Avenue, La Grande, Oreg.

Once a planning interval is in hand, this determines the the magnitude of the various rates which are used in the equations for the model. Here is a list of these rates:

P_d = the probability that a snag in diameter class d will remain standing over 1 time interval (this is 1-Fall Rate)

M_d = the probability that a live tree in diameter class d will die over 1 time interval

Q_d = the probability that a live tree in diameter class d will move to diameter class $d+1$ in 1 time interval

R_d = the probability that a tree in diameter class d will remain in diameter class d over 1 time interval

As is obvious, there is a heavy emphasis placed on a diameter structure for the model. There are reasons for this. First, it is a fact that there are definite preferences among certain species of woodpecker, for example, for snags that are of a certain minimum diameter (Thomas 1979). Wildlife management for such species thus requires insight into the diameter composition of the available snag habitat.

Second, existing studies (Keen 1955, Dahms 1949, VanSickle 1978, Lyon 1977, Bull in publication) have shown that, in general, snag fall rates follow a nonlinear pattern by diameter class. This is to say that we cannot expect a snag in the 10-20" class to stay up half as long on the average as a snag in the 20-30" class. The reality is that trees that are about twice as big across stay up more than twice as long.

In the same fashion, transition rates for live trees from one diameter class to the next are nonlinear (i.e. big trees have less diameter increment than small trees over the same time interval). So one equation for all of the diameter classes will not do. That is why we emphasize the diameter structure.

Defining the Equations

The Snag Equation

The snag equation is quite simple to state. To determine the number of snags in a given diameter class at the start of a planning interval, we start with the number of snags that remain standing from the start of the last planning interval. To this we add the number of live trees that were in that diameter class during the previous interval which we would expect to die off. So the snag pool is made up of recruits from the living population and

veterans from the snag population. In mathematical terms, the equation is:

$$S_d(n+1) = S_d(n) \times P_d + T_d(n) \times M_d$$

P_d and M_d are as described previously, while $S_d(n)$ and $T_d(n)$ represent, respectively, the number of snags and the number of live trees in diameter class d at the start of time interval n .

Suppose we know that at time 0 we have, for the 10-20" diameter class which we will arbitrarily call class 2, a certain number of snags and live trees of that diameter class ($S_2(0)$ and $T_2(0)$). We would like to project the number of snags in this class 10 years, or 1 time interval, into the future. Then:

$$S_2(1) = S_2(0) \times P_2 + T_2(0) \times M_2$$

If we now assume that we have a way of obtaining the number of live trees that will be available at the start of time interval 1 for that diameter class we may then project 20 years into the future by calculating:

$$S_2(2) = S_2(1) \times P_2 + T_2(1) \times M_2$$

Thus, recursive calculations can be used to estimate the number of snags in each diameter class for successive time intervals.

The Live Tree Equation

Somewhat more tenuously, we may write down a simple equation to project live tree growth over time so that we might continue to update the snag equation described above. This equation starts with the number of live trees in a given diameter class which are available at the beginning of a time interval and which might be expected to remain in that diameter class over the interval ($T_d(n) \times R_d$). To this is added the number of trees from the immediately preceding diameter class which would grow into this diameter class during the time interval ($T_{d-1}(n) \times Q_{d-1}$). The equation is:

$$T_d(n+1) = T_d(n) \times R_d + T_{d-1}(n) \times Q_{d-1}$$

At this point, we should pause to examine more closely the equations stated above. There are certain implicit assumptions which limit their usefulness. This is especially true for the second, or live tree, equation. This is not as crucial as it might first appear, however, since there exist far superior models to predict tree growth. One such model, the Stand Prognosis Model (Stage 1982), will be discussed below. Access to such a model would preclude the need to make use of the live tree equation, since mortality figures could be obtained directly from this more comprehensive modelling process.

The real value of this live tree equation may be in its ability to mimic the much more complicated processes of models like the Stand Prognosis Model (SPM). In situations where there is a specific management regime imposed on a stand, the live tree equation seems to hold very closely to the growth estimates of the stand prognosis model. The relationship between the live tree equation given above and models like the SPM could be the subject of future research.

Assumptions

At this point we would do well to list the assumptions we have made in developing the above system of equations. Specifically, we have assumed that the rate factors are constants, independent of stand density or distribution. While this may have validity for the snag retention rates (P) (this may be less applicable where the stand has been opened up and windthrow becomes a factor), it would seem to have less merit for calculating mortality (M).

A potentially more serious problem arises with the so called transition rates, Q and R. Stocking density will have a definite impact on these rates. In the SPM, for example, diameter growth for a specific tree is made functionally dependent upon the total basal area/acre of all trees greater in diameter than the target tree. In other words, for a given diameter class, Q and R are not constant but are density dependent parameters.

While these limiting assumptions might seem to limit usefulness of the live tree equation, in fact, this is not the case. Let us consider managed stands, for example.

Example

In managed stands, periodic thinnings insure that individual trees have enough growing space to minimize competition. We might then expect the transition factors, Q and R, to be more nearly constant. When the live tree equation was fitted to the SPM predicted values for a managed stand,³ and the resulting rate factors used in the live tree equation, the results were quite close to the SPM predicted values (table 1).

Values for S, M, R and Q for both diameter classes were obtained using regression techniques with data from the SPM model. With these estimators, the model equations could be updated as a system. The resulting values for

Table 1.--Comparison of predicted number of live trees by diameter class over a 100 year period for the SPM and live tree equations (LTE).

Year	Predicted no. of trees by diameter class SPM/LTE	
	10"-20"	>20"
70	29 / 29	0 / 0
80	23 / 23	4 / 4
90	18 / 16	6 / 8
100	11 / 10	11 / 11
110	5 / 7	15 / 14
120	2 / 4	16 / 14
130	0 / 3	17 / 15
140	0 / 2	16 / 16
150	0 / 1	14 / 15
160	0 / 1	13 / 15

snag levels (per acre) for the 10"-20" and >20" classes are outlined in table 2.

The transition rates (Q and R) were obtained from a fit of data for the SPM predicted live tree numbers of table 1. Mortality for the live trees (M) was a by-product of this fit and, along with snag retention rates (P), was used to continuously update the snag equation to produce table 2.

To summarize, if the user has access to reliable estimates of stand distribution by diameter class over time, or better yet actual mortality figures by diameter class over time, then these, when combined with snag fall rates and a set of initial stand conditions, allow for an estimate of snag distribution, by diameter class over time.

In lieu of actual mortality figures in our example, we estimated the mortality rates, snag retention rates and transition rates, based on outputs from the SPM and produced the simulated live tree and snag numbers from the equations presented here.

DISCUSSION

Any model such as this one must be subject to intense scrutiny. As a first step, it is in need of field validation, as opposed to validation based on another model, such as the

³Obtained from the Wallowa Valley Ranger District of the Wallowa-Whitman National Forest, Joseph, Oregon.

Table 2.--Snag numbers over a 100 year period for two diameter classes.

Year	Number of snags by diameter class	
	10"-20"	>20"
70	0.0	0.0
80	2.6	0.0
90	3.3	0.1
100	2.9	0.3
110	2.2	0.5
120	1.5	0.6
130	1.0	0.8
140	0.7	0.9
150	0.4	1.0
160	0.3	1.1

SPM. This is especially true of the snag levels, since the SPM does not project these figures at all. In fact one of the recommendations that I would like to make is that models such as the Stand Prognosis Model have incorporated into them a simple equation to project snag levels. But first there must be validation.

In addition, data collection efforts should center on the determination of snag retention rates. These are of the utmost importance to accurate predictions of snag levels. This determination should be made for all tree species and diameter classes which are of importance to wildlife managers as potential habitat. At the very least, a literature search should be conducted to obtain all of those studies for which these rates might be computed.

A useful source of future determination of snag retention rates might be the existing forest inventory stands managed by the U.S. Forest Service. These inventories in the Blue Mountains track the number of downed snags. But there is no tagging, by diameter class or otherwise, and thus no possibility of determining over what period a specific snag may have fallen. If the inventory process could be modified to incorporate this knowledge then a large step would have been taken in gathering accurate data for the prediction of snag levels.

I am convinced that with this important bit of information a simple model like the one described above would allow for reasonable

estimates of the number of snags available over time, by species and diameter class. This would provide a starting point for maintenance of viable amounts of habitat for the many cavity users.

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Providing Snag Habitat for the Future¹

Keith A. Menasco²

Abstract.--Two green trees in addition to 1.8 snags should be adequate to maintain sufficient snag numbers during a timber rotation. If a sufficient number of snags are not present then snags must be artificially created or more green trees must be retained. The amount of timber volume lost to provide snag habitat will amount to 4 percent of the total volume.

INTRODUCTION

Snag dependent bird species can account for as much as 30 to 45 percent of the total bird population and may account for as much as 66 percent (Scott et al. 1980). These species are primarily insectivorous and are vital in the role of insect control (Thomas et al. 1979; Jackson 1979; Kroll and Fleet 1979; and many others). They are also important for aesthetic and ecological roles (Peterson 1980).

Articles have been written on the value of snags, sizes of snags selected by certain species of cavity-nesting birds, and an approach to determining quantitative numbers and sizes of snags to meet different needs of maximum potential woodpecker populations. Thomas et al. (1979) has compiled much of what is presently known about snag management.

I have written this paper to answer some basic questions in order to provide adequate snag habitat both now and in the future for snag dependent wildlife species. The Tonto National Forest, like many forests, has timber stands which are now being treated with a final removal cut (shelterwood harvest) which will eliminate the last of the yellow pines (large mature ponderosa pine, *Pinus ponderosa*) remaining in the overstory. The wildlife manager must know what the snag requirements are for his locality and must decide on the number and sizes of trees to be retained to provide for snag recruitment during the next timber rotation.

SNAG REQUIREMENTS

The Tonto National Forest has 5 primary cavity-nesters (Table 1). Using the model developed by

Thomas et al. (1979), the number of snags required to meet the needs of all 5 species was determined (Table 2). Like Thomas et al. (1979), it was assumed that if the needs of the primary excavators were met then the requirements for all cavity users will also be met. Population levels below 40 percent of maximum potential were not considered viable (Thomas et al. 1979). Snags smaller than 15 inch DBH are used, however, they are used less than larger ones (Scott 1978). Therefore, I considered them of less importance and only snags greater than 15 inches were considered. All of the primary cavity-nesters found on the Tonto will nest in snags less than 20 inches. However, the acorn woodpecker, *Melanerpes formicivorus*, has additional snag requirements for food storage (granary trees). Acorn woodpeckers will select the largest snags in the area as their granary trees and these trees will average greater than 20 inches (Gutierrez and Koenig 1978; Trail 1980). It is not known if acorn woodpecker populations will be suppressed if there are no snags greater than 20 inches. However, it is believed that snag size is limiting and that acorn woodpecker populations will be suppressed if there are no snags greater than 20 inches (Walter D. Koenig, pers. comm.).³ Therefore, I have included the acorn woodpecker's requirement for granary trees when computing snag numbers and I have assumed that acorn woodpeckers require snags in excess of 20 inches for granary trees.

Under present timber management direction we are managing timber on a 120 year rotation with the objective of growing and harvesting 18 to 20 inch trees. If we do not leave trees to grow larger than 20 inches then this size class of snags will be eliminated. Due to our limited understanding of the intricacies of forest communities I believe it would be a mistake to ever deliberately manage populations at a minimum viable level (40 percent). To allow for error I have used the 50 percent level as a minimum level.

¹Paper presented at the Snag Habitat Management Symposium, Flagstaff, Arizona, June 7-9, 1983.

²Keith A. Menasco is a Wildlife Biologist, Tonto National Forest, Payson, Ariz.

³Koenig, Walter D. 1983. Personal conversation. Hastings Reservation, Univ. Calif., Berkeley.

Table 1.--Habitat requirements for the 5 primary cavity nesters found on the Tonto National Forest

	Min. Snag DBH in inches	No. Cavities excavated/year	Max. Pairs/100 acres	Snags required per 100 acres to support various percentages of maximum woodpecker populations. ⁶									
				100%	90%	80%	70%	60%	50%	40%	30%	20%	10%
Acorn Woodpecker	≥20 ⁽⁵⁾	3 ⁽⁵⁾	3.8 ⁽⁴⁾										
	≥10 ⁽³⁾	1 ⁽³⁾		171	154	137	120	103	86	68	51	34	17
Common Flicker	≥12 ^(2,3)	1 ^(2,3)	2.5 ⁽²⁾	38	34	30	26	23	19	15	11	8	4
Hairy Woodpecker ⁽¹⁾		1 ⁽³⁾	4 ⁽²⁾										
		3 ⁽²⁾		180	162	144	126	108	90	72	54	36	18
Lewis Woodpecker	≥12 ⁽³⁾	1 ^(2,3)	6.7 ⁽²⁾										
	≥15 ⁽²⁾			101	90	80	70	60	50	40	30	20	10
Williamson's Sapsucker	≥12 ^(2,3)	1 ^(2,3)	20 ⁽²⁾	150	135	120	105	90	75	60	45	30	15

¹Indicator species for Tonto National Forest.

²Thomas et al. 1979.

³Bull 1978.

⁴Used territory size of 26.3 (Trail 1980 because of lack of density and diversity of oaks in ponderosa pine type.

⁵Acorn woodpeckers require granary trees that averaged greater than 20 in. DBH (Trail 1980; Gutierrez and Koenig 1978). Number of activities excavated also include trees required for granaries.

⁶Number of snags computed using the formula: $S = C(16-1)N$. Where pairs 100 acres (Thomas et al. 1979).

Table 2.--Total number of snags required per 100 acres by size class to support various percentages of maximum woodpecker populations for all 5 species of primary excavators found on the Tonto National Forest. Note: Large snags may be substituted for smaller ones when deriving total snag numbers.

	100%	90%	80%	70%	60%	50%	40% ⁽²⁾	30%	20%	10%
≥20" DBH	171	154	137	120	103	86	68	51	34	17
≥15" DBH ¹	9	8	7	6	5	4	4	3	2	1
TOTAL	180	162	144	126	108	90	72	54	36	18

¹A minimum of 15" DBH was used based on study by Scott (1978) that found a significantly higher use in snags ≥ 15" DBH

²Minimum viable population.

There is a noticeable lack of snags present today on the Tonto because, prior to 1973, snags were routinely cut. No intensive surveys have been conducted, however, it is estimated that there are approximately only 50 snags per 100 acres (>15 in. DBH) in managed stands. Timber found on slopes too steep for conventional logging methods probably have in excess of 180 snags per 100 acres.

SNAG DENSITIES

To determine the number and sizes of trees to be retained during a final removal shelterwood cut it is necessary to predict snag numbers. Bull et al. (1980) developed a model that predicts the number of snags present at any given year providing that the beginning snag and tree density, annual fall rate of snags and annual mortality of green trees are known. For simplification Norm Cimon (pers. comm.)⁴ modified the model for use with a programmable hand held calculator. The modified model is presented below.

$$S_n = (S_o - \frac{T_o M}{F-M} \times (1-F)^n) + (\frac{T_o M}{F-M} \times (1-M)^n).$$

Where: S_n = snag number in the nth year
 S_o = snag density at year zero
 T_o = green tree density at year zero
 M = mortality rate of green trees
 F = falling rate of snags
 n = the year

Inherent model deficiencies are that all size classes, annual mortality of green trees, and falling rate of snags are static when in reality size classes change over time, mortality increases with age (size) and falling rates of snags vary with age and size.

Densities of green trees required for snag recruitment to maintain viable wildlife populations during a 120 year timber rotation were determined using the above model. The number of snags was predicted for each tenth year using different initial densities of residual green trees. I have assumed that a sawtimber sale will be conducted at year 70, 90, and 110 and 90, 50, and 35 trees, respectively, will remain following harvest. At year 130 there will be either a removal or a seed cut. Mortality rates for green ponderosa pine trees were determined using a model developed by Kasmussen and Ffolliott⁵ (Table 3). The model was developed using data from the Continuous Forest Inventory (1960-70) for the Southwestern Region of the USDA Forest Service. To make the snag prediction model respon-

Table 3.--Annual mortality rates of ponderosa pine by size classes for the Southwest.

Tree size by DBH in inches	Annual mort. rates	Tree size by DBH in inches	Annual mort. rates
15	0.36	24	0.54
16	0.37	25	0.57
17	0.38	26	0.60
18	0.40	27	0.64
19	0.41	28	0.68
20	0.43	29	0.73
21	0.46	30	0.77
22	0.48	31	0.82
23	0.51		

sive to an increase in size with age it was assumed that a 20 inch ponderosa pine tree would grow at an average increment of 1 inch during each decade.

The rate of fall for snags depends primarily on the time elapsed since death (age). However, the rate also depends on the size of the snag and the environmental conditions (Keen 1955). Both Keen (1955) and Cunningham et al. (1980) found a rapid falling rate at first which slows with time. Keen (1955) found that only the large snags will persist. Bull et al. (1980) reported that 10 to 20 inch snags had a rate of fall more than 7 times greater than snags larger than 20 inches. Cunningham et al. (1980) did not compare rate of fall with size. The snags studied by Cunningham et al. (1980) in the Southwest persisted much longer and, therefore, had a lower falling rate than those studied by Keen (1955) or the falling rates used by Bull et al. (1980). This was attributed to a dryer climate (Cunningham et al. 1980).

At any one time there will be snags with different ages and sizes and, therefore, with different falling rates. To utilize the snag prediction model it is necessary to have a constant or annual falling rate. Cunningham et al. (1980) found the relation between age and percent standing to be curvilinear. To derive the "best fit" annual fall rate I fitted the best straight line to the data reported by Cunningham et al. (1980) using a linear regression equation. The slope of this line (1.48) was used as the annual falling rate for snags. Because Cunningham et al. (1980) did not include size, the falling rate of 1.48 percent was used only for snags greater than 20 inch DBH. A falling rate 7 times greater (10.3 percent) was used for snags less than 20 inches (Bull et al. 1980).

Using a falling rate of 1.48 percent, 2 green trees (>20 in. DBH) in addition to 1.8 snags (>20 in. DBH) per acre will maintain enough snags throughout the rotation for viable populations (Fig. 1). However, if there are only 0.5 snags per acre as is the present condition over much of the Tonto then the population will remain suppressed below minimum viable levels (40 percent) until the stand reaches an adequate size level to begin producing snags on its own. Species requiring greater than 20 inch DBH snags will remain suppressed throughout the whole rotation until the stand averages 20 inches (Fig. 2).

⁴Cimon, Norm. 1983. Personal correspondence. USDA Forest Service, Range and Wildl. Habitat Lab., La Grande, Oregon.

⁵Rasmussen, William O. and Peter F. Ffolliott. (n.d.) A model to predict snag development. Unpublished manuscript. School of Renewable Natural Resources, Univ. of Ariz., Tucson.

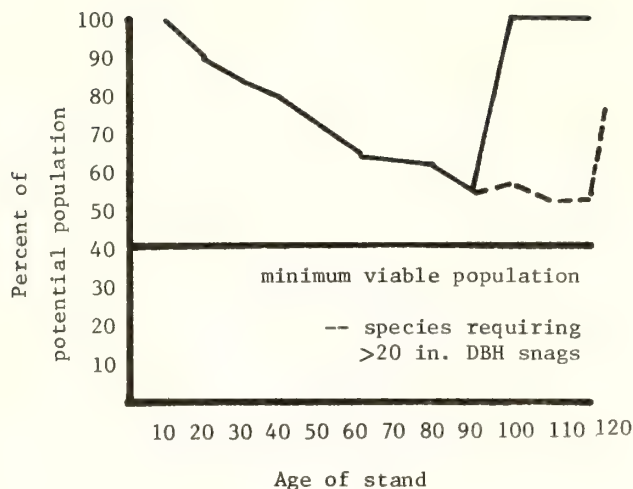


Figure 1.--Percent of potential population existing over time beginning with 1.8 snags plus 2 green trees (all greater than 20 in. DBH). Stand will average 15 inch DBH at year 90 and 20 inch DBH at year 120.

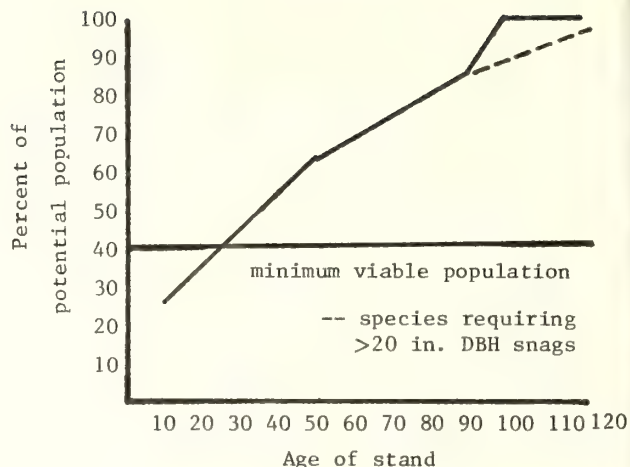


Figure 3.--Percent of potential population existing over time beginning with 0.5 snags plus 6 green trees per acre (all greater than 20 in. DBH). Stand will average 15 inch DBH at year 90 and 20 inch DBH at year 120.

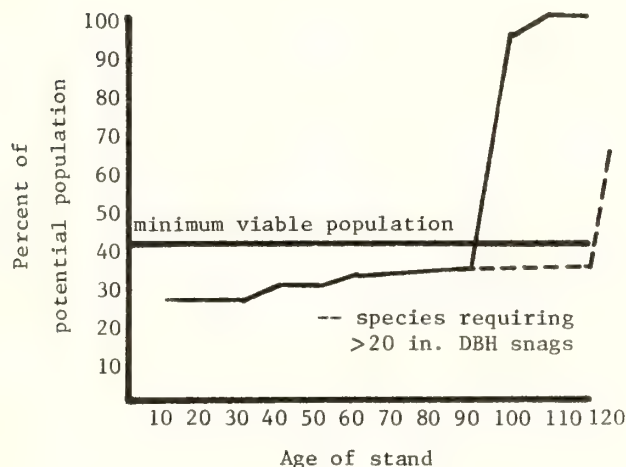


Figure 2.--Percent of potential population existing over time beginning with 0.5 snags plus 2 green trees per acre (all greater than 20 in. DBH). Stand will average 15 inch DBH at year 90 and 20 inch DBH at year 120.

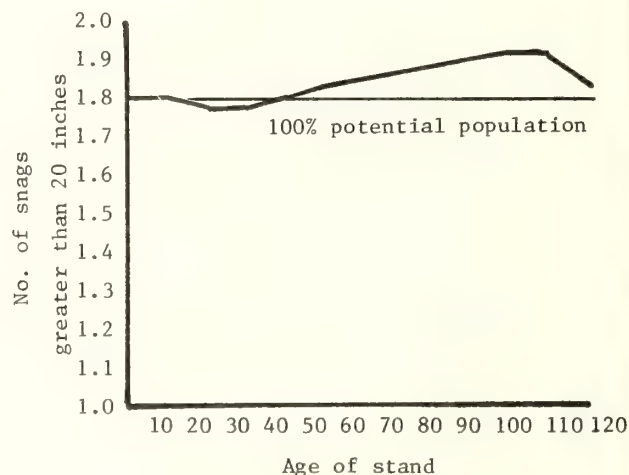


Figure 4.--The number of snags existing over time beginning with 1.8 snags and 6 green trees per acre (all greater than 20 inch DBH). There will be additional snags in the 15-20 inch DBH size class beginning at year 90.

The manager has 2 options to alleviate this problem. Either snags can be artificially produced or more green trees can be retained to accelerate snag recruitment. If 6 trees are retained the potential population will increase above the minimum viable level in 15 years (Fig. 3). If 4 trees are left it will take almost 50 years. To maintain snag levels at 1.8 snags (20 inch DBH) per acre it will require the retention of only 6 trees per acre (Fig. 4).

ECONOMICS

Using RMYLD computer programming (Edminster 1978) yields were calculated for an entire rotation to determine what percent of the total volume was being lost for snag recruitment (Table 4). A theoretical even-aged, one-storied stand was used based on a site index of 70. Calculations were initiated when the stand was 40 years old, with a basal area of 79 square feet, and an average DBH of 6 inches. Thinnings were scheduled at 20 year intervals. The stand was free of dwarf mistletoe.

Table 4.--The amount of timber volume lost during a rotation for the purpose of providing residual trees for snag replacement.

No. of trees	DBH (in.)	Vol. lost cu. ft.	Total vol. harvested cu. ft.	Stand age at last cutting	Percent lost
2	21.7	152	3818	120	4.0
3	21.7	228	3742	120	6.1
6	18.5	300	3290	100	9.1

CONCLUSIONS

It is important to have adequate snag numbers when going into a new timber rotation. With adequate snag numbers initially, it will only require 2 green trees in excess of 20 inches for a loss of only 4 percent of the total timber volume for that rotation.

The predictions made in this paper are only as good as the data used in the model. I feel comfortable with the mortality data, however, I do not with the snag falling rate data. More research is needed to determine true falling rates. The data reported by Cunningham et al. (1980) were collected in a mature forest situation. I believe the falling rates will be much higher for snags that are widely spaced and exposed, such as in stands that are composed of saplings. I cannot overemphasize the significance of this. If a falling rate of 3.2 percent (falling rate in Pacific Northwest, Bull et al. 1980) is used it will require 6 trees per acre instead of 2 and it will be infeasible to leave enough residual trees in a managed stand to maintain 1.8 snags per acre for the duration of the stand. An increase in residual trees means a larger trade-off.

Other factors that must be considered are rate of blow-downs for the residual trees left for snag recruitment and amount of theft occurring on present snags for firewood. Once a stand is regenerated it will not be able to produce snags of sufficient size for approximately 80 years. Any impacts on the residual green trees or snags must be foreseen or there may be a shortage of snags during a time when nothing can be done until the stand again reaches an average size large enough for wildlife snag requirements.

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Cavity-Nesting Bird Response to Declining Snags on a Burned Forest: A Simulation Model¹

Martin G. Raphael²

Abstract.--I present a simple model to estimate population sizes of primary (PCN) and secondary (SCN) cavity nesting birds in relation to a declining snag population following fire. The model assumes that PCN are limited by snag suitability, intraspecific territoriality, or snag density during successive time periods. Two examples illustrate these patterns, as well as the impact of snag harvest on subsequent bird populations. A FORTRAN program, CNBIRDS, performs all computations.

INTRODUCTION

Snags are a dynamic resource: their populations undergo temporal changes in both quality (snags decay with age) and quantity (new snags appear and existing snags fall with time). Little attention has been focused on the implications of these temporal trends for wildlife. The snag management model developed by Thomas et al. (1979), for example, gave estimates of the numbers and sizes of snags required by woodpeckers, but failed to take into account attrition of snags with time. Bull et al. (1980) have, however, presented a formula for estimating the future density of snags given their annual falling rate and starting density. In this paper I extend the latter approach using a computer simulation model (CNBIRDS) to track numbers of snags and to estimate resulting numbers of primary (PCN) and secondary (SCN) cavity-nesting birds through time as snags decay and fall. Using a burned Sierra Nevada pine-fir forest as an example, I examine the response of birds to reduced densities of snags with time under both natural and managed conditions.

THE MODEL

To construct the model, I considered 8 combinations of snag dbh and species. Starting values for the number of snags present in each category are decreased each year by a proportion calculated

using a generalized poisson distribution function for each category. The shapes of these decay curves were adjusted to match empirical data reported by Raphael and White (in press).

At the start of each year PCN are added to the system, subject to several constraints. First, the model assumes that each pair of PCN requires a specified minimum number of snags. Secondly, each PCN has a maximum population size determined by intraspecific territoriality. Maximum values used in this model were based on average densities from published breeding censuses (Raphael and White 1978) for each of the 8 species likely to nest in burned pine fir forest of the Sierra Nevada (Table 1). Thirdly, I modeled the proportion of each species' nests expected in each of the 8 snag categories (Table 1). Finally, each species requires snags in a particular range of decay-states; the model incorporates a minimum snag age before snags become acceptable, under the assumption that age and decay are directly related.

The population of SCN was modeled assuming that numbers are limited by either the number of suitable cavities or a fixed maximum, again based on intraspecific territoriality. The number of suitable cavities in each snag type resulted from the following considerations. First, each PCN excavates from 1-3 cavities per year (see Bull et al. 1980). The model assumes that all cavities, except those of Pygmy Nuthatch, are available to SCN. Next, the current year's cavities are added to those that exist from the previous year in each snag type. With the passage of a year, a number of these cavities are lost as the snags containing them fall; this number of lost cavities is proportional to the annual rate of fall of each snag type. Finally, the number of cavities at the start of the next year is used to set the potential number of SCN. If this potential exceeds the previously specified maximum density (read in as an input item), the model sets the current population

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²Martin G. Raphael is Staff Research Associate, Department of Forestry and Resource Management, University of California, Berkeley, California 94720.

Table 1.--Proportion of nests expected in each combination of snag species and diameter class (dbh, cm), maximum density of PCN, and initial snag densities.¹

Bird Species	Fir ²				Pine ³				Sample size ⁴	Maximum density (pairs/100 ha)
	<23	23-37	38-53	>53	<23	23-37	38-53	>53		
Pygmy Nuthatch (<i>Sitta pygmaea</i>)	0	0.36	0.21	0.14	0	0.07	0.11	0.11	28	57.6
Hairy Woodpecker (<i>Picoides villosus</i>)	0	0.22	0.30	0	0	0.13	0.22	0.13	23	12.4
Black-backed Woodpecker (<i>Picoides arcticus</i>)	0	0.12	0.13	0.12	0	0.38	0.25	0	8	1.0
Red-breasted Sapsucker (<i>Sphyrapicus ruber</i>)	0	0.04	0.07	0.56	0	0	0.04	0.29	45	4.0
Williamson's Sapsucker (<i>Sphyrapicus thyroideus</i>)	0	0	0.04	0.45	0	0.02	0.08	0.41	49	4.0
White-headed Woodpecker (<i>Picoides albolarvatus</i>)	0	0.08	0.25	0.34	0	0.08	0.08	0.17	12	5.7
Northern Flicker (<i>Colaptes auratus</i>)	0	0.11	0.21	0.20	0	0.03	0.17	0.28	65	7.2
Lewis' Woodpecker (<i>Melanerpes lewis</i>)	0	0	0.16	0.38	0	0	0.22	0.24	37	7.2
Initial density of snags (N/100 ha)	4472	5300	1455	402	4413	6684	1987	260		

¹Data from Raphael and White (1978), Raphael and White (in press), and Raphael (unpublished).

²Includes *Abies concolor*, *A. magnifica*.

³Includes *Pinus contorta*, *P. jeffreyi*, *P. ponderosae*.

⁴Number of nests examined to calculate proportion.

to that maximum, and there are surplus (unused) cavities.

The major features of the model are summarized in Figure 1. Basically, with the passage of each year a proportion of snags fall. The remaining snags are counted in each type and the program calculates the numbers of PCN and SCN for the current year. When all snags have fallen (or when the number of years reaches a preset maximum), the program stops. This is a simple model, but, as I hope to show with the following examples, a potentially useful one.

EXAMPLE ONE: NO TREATMENT

Snag Decline

The first example is designed to examine the reponse of cavity-nesting birds to the pattern of snag-fall on a burned forest assuming that no snags are harvested following the burn. The model was run for 45 years. I specified that each pair of PCN required at least 48 snags (from Thomas et al. 1976) and that each PCN excavated only 1 cavity per year. I also set the maximum density of SCN at 240 pairs per 100 ha (calculated from the upper 95% confidence interval of the mean breeding density of SCN from 63 censuses published in *American Birds* [Jackman 1974]). Starting values for the number of snags in each category (Table 1)

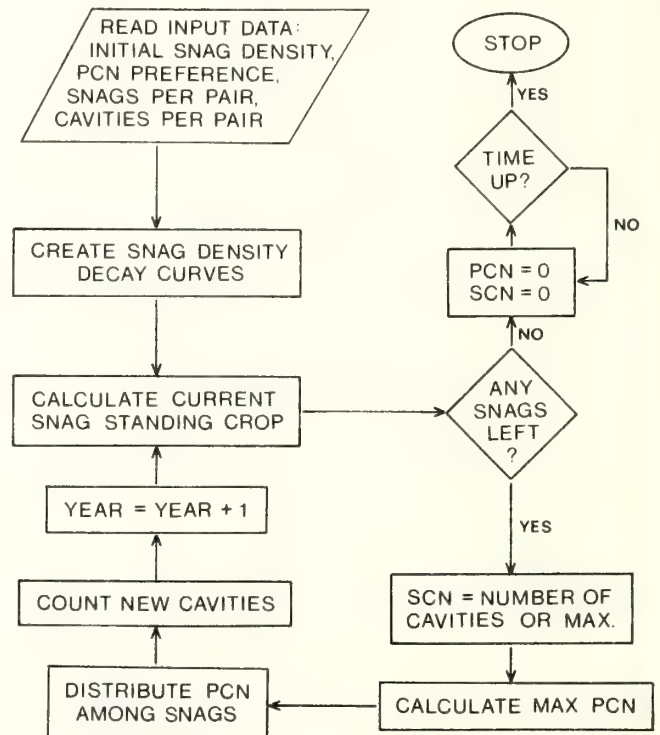


Figure 1.--General flow chart for program CNBIRDS. Data on snag decay rates and use by PCN and SCN are maintained separately for each of 8 snag size and species combinations (see Table 1).

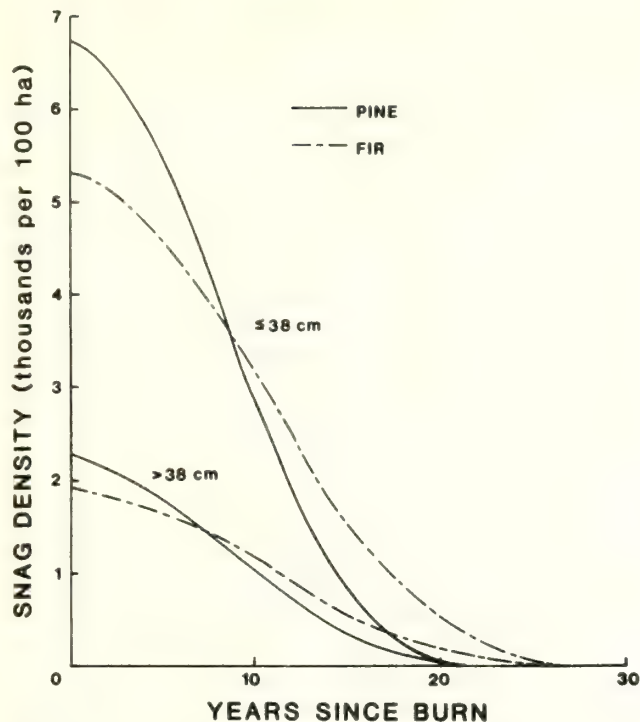


Figure 2.--Simulated decline of snag density following fire, by species and dbh class. Snags less than 23 cm dbh are not included.

were determined from field data (Raphael and White, in press).

Fifty percent of the snags fell by the first 10 years (Fig. 2); the falling rate slowed thereafter. Larger snags fell at a slower rate than smaller ones, and fir snags fell slower than pine (Fig. 2). By year 20 nearly all of the pine snags had fallen; by year 25 nearly all the fir snags had fallen. By year 35, no snags were left.

Bird Response

The simulated response of cavity-nesting birds (Fig. 3) revealed several interesting

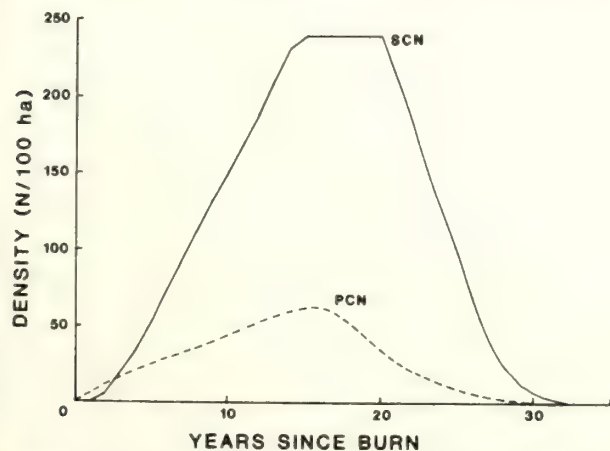


Figure 3.--Simulated response of cavity-nesting birds to changing snag density following fire.

patterns. First, density of PCN did not reach a maximum until year 18. Until then, snags were abundant but bird numbers were limited by the lack of sufficiently decayed snags or by their territoriality. The differential responses of selected PCN species are illustrated in Figure 4. Hairy Woodpeckers are opportunistic species that rapidly invade burned forests (Koplin 1969) and are capable of excavating nests in harder (more recently killed) snags (Raphael and White, in press). Northern Flicker and Lewis' Woodpecker require softer snags for nesting; these species do not reach maximum densities until year 15 and 19, respectively (Fig. 4). Other species (not illustrated) achieved maximum densities at intermediate years.

Beyond 18 years, snags were sufficiently decayed for all species, but snag density had become too low to support maximum densities of PCN. The PCN population crashed as snag numbers were further reduced; none remained by year 30.

The populations of SCN lagged behind the PCN for the first 2 years, until the supply of cavities began to build up. Thereafter, SCN numbers rose rapidly due to the accelerating rate of cavity production and the larger inventory of cavities persisting from previous years. Maximum density was reached in year 16, 2 years earlier than achievement of maximum density of PCN. The SCN maximum persisted until year 22. During this period, the model assumed that SCN were limited by territoriality rather than availability of cavities. Beyond year 22, the accelerating rate of snag fall caused the number of cavities to decline to the extent that SCN were again limited by cavity availability. It is interesting that the SCN persisted at maximum density for 3-4 years beyond the year when PCN began declining. Apparently, PCN became limited by numbers of suitable snags while SCN were still finding surplus cavities present from previous years. This is an easily tested prediction resulting from the model.

I used the periodic breeding census from a burned study plot at Sagehen Creek to test this prediction. Ten censuses are available, covering the period from 6 to 22 years following fire (Bock and Lynch (1970, Bock et al. 1978, Harris and Raphael 1982, Yoder-Williams, in press). Unfor-

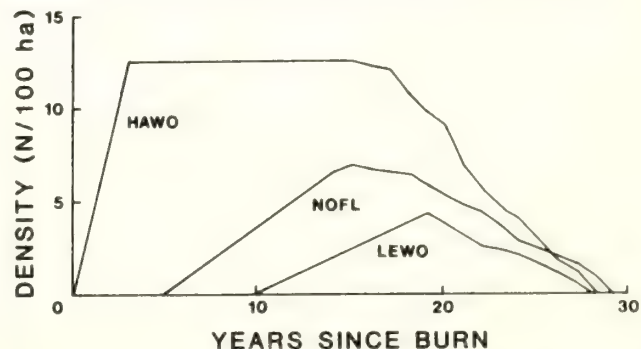


Figure 4.--Response of selected PCN to changing snag density following fire. Species are Hairy Woodpecker (HAWO), Northern Flicker (NOFL), and Lewis' Woodpecker (LEWO)

tunately, the census data do not support the model prediction (Fig. 5). Both PCN and SCN declined at nearly the same rate over this 15 year period. Perhaps the model is wrong, or perhaps the small size of the study grid (8.5 ha) results in such exaggerated year-to-year variation that subtle differences are masked. In addition, comparison of figures 3 and 5 shows that modeled population sizes of PCN and especially SCN are higher than those actually estimated from the censuses. Further monitoring of this plot, and comparison with other long-term censuses on burned plots will be necessary to validate model predictions.

One obvious result of this exercise is an explicit demonstration of the futility of using ratios of the number of snags with cavities to the number without cavities as an estimate of the snag requirements of PCN, as has been suggested by Thomas et al. (1979). Reference to Figure 3 shows that this ratio will change constantly with the history of the plot. In year 1, for example, only a few snags will have cavities. In year 25, however, probably 100% of the remaining snags will contain at least one cavity. Thus, conclusions resting on such ratios must be tempered with knowledge of the age of the snags on the study plots.

EXAMPLE TWO: EFFECTS OF SNAG HARVEST

Program CNBIRDS can also be used to explore impacts of snag treatments on cavity-nesting birds. In this section I examine the response of birds to reduced initial densities of snags, simulating various snag harvest levels immediately following fire. My measure of bird response was derived from the accumulated total number of birds (both PCN and

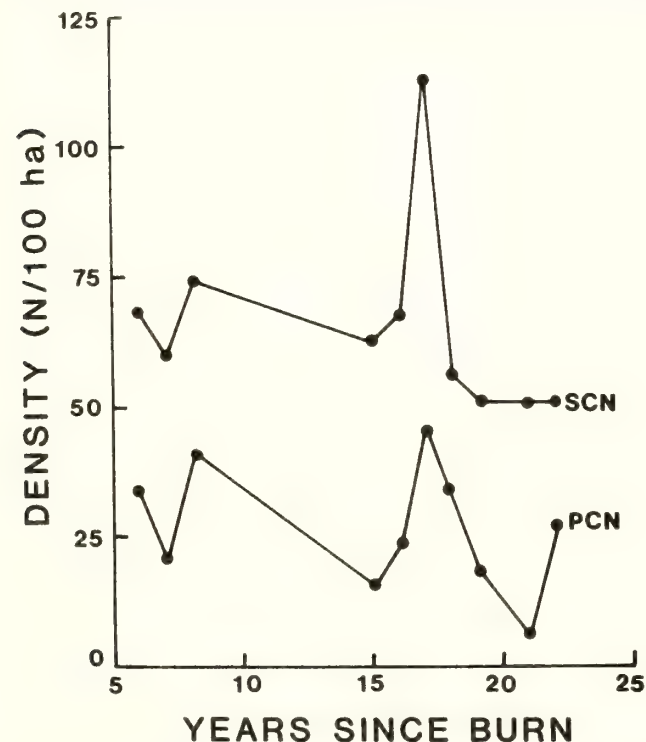


Figure 5.--Censused density of cavity-nesting birds following fire on a Sierra Nevada forest.

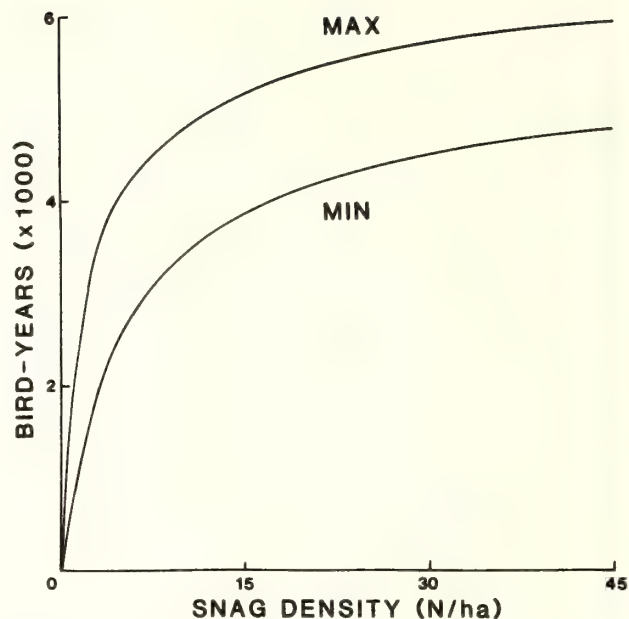


Figure 6.--Simulated response of cavity-nesting birds to changing initial density of snags greater than 38 cm dbh. The upper curve (max) was computed assuming that each pair of PCN requires 15 snags and excavates 3 cavities per year; the lower curve (min) assumes 48 snags per pair and 1 cavity.

SCN) over all years. For each run, this amounted to an integration of the curves illustrated in Figure 2. If, for example, 5 pairs existed in each of 4 years, the total bird-years would equal 20.

I used 19 snag treatment levels. These varied from 1% to 10% of the pretreatment snag density (in 1% increments) and from 20% to 100% (in 10% increments). I also varied 2 of the major model assumptions: the number of cavities excavated per pair could be 1, 2, or 3 and the number of snags required per pair could be either 15 or 48. Thus, I ran the model a total of 114 times to include all possible combinations of snag density, snag requirements, and cavities excavated.

Total bird-years rose dramatically from the 0 to 10% treatment level, corresponding to 0 to 4.5 snags >38 cm per ha (Fig. 6). The maximum number of bird-years for any particular snag density occurred where I assumed a snag requirement of only 15 per pair and a cavity excavation rate of 3 per pair. The lowest response occurred under assumptions of 48 snags and 1 cavity per pair. Because all other combinations yielded intermediate values, I display only these extremes. Beyond the 15 snags per ha (30%) level, bird response rose relatively slowly. The model predicted, then, that optimum snag densities under the present constraints should be between 7 and 15 snags per ha. I find it significant that tripling the assumed snag requirements and cavity production resulted in about only a 17% decrease in bird use at any snag density. It would appear that birds are much more sensitive to changes in snag density than variation of model parameters within the range I tested.

CONCLUSIONS

Program CNBIRDS seems to be a useful model to examine relationships between numbers of snags and numbers of cavity nesting birds and changes in both that occur through time when snags are not replaced. The model can be used to develop a number of testable hypotheses regarding the relative numbers of PCN and SCN and their respective rates of increase and decrease with time. Even if the model proves unrealistic, it can be useful as a classroom tool to demonstrate a simple but thought-provoking example of the coupling between wildlife populations and their habitats. Finally, the program can be used to examine the potential consequences of harvesting any proportion of any combination of snag diameter, and species.

A listing of program CNBIRDS, which is written in FORTRAN IV for CDC machines and consists of a main program and 8 subroutines, is available from the author in request.

ACKNOWLEDGMENTS

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Predictive Models for Snag Nesting Birds¹

Russell P. Balda, William S. Gaud, Jeffrey D. Brawn²

Abstract.--Multiple regression models were developed and their predictive power tested for the five common secondary cavity nesting birds in the ponderosa pine forests. Variables included in the regression analysis included seven vegetation ones and 11 climatic ones. All models were highly significant and explained between 50 and 89 percent of the variation in breeding bird density. Snag density, which appeared as an important variable in four of five models, had a positive affect on breeding bird density. Snags are the most important variable determining density of most of the secondary cavity nesters.

INTRODUCTION

Populations of animals demonstrate, by their densities and reproductive output, a complex set of responses to a vast array of environmental variables. Theoretically, when resource levels are high and conditions hospitable, populations should show a numerical response and increase. Opposite conditions should cause a decrease. In practice, however, the interactive complexity of the factors affecting populations make it difficult, and at times, impossible to understand the underlying causes of population fluctuations. As Karr (1980) points out, temperature-moisture regimes, seasonality, vegetation structure, food resources, interspecific coevolutionary forces, and resource utilization patterns, all may interact in a complex manner to determine community structure. Biogeographic phenomena must also be considered, as a species that has not encountered a specific habitat type cannot be a candidate to breed there. Social interactions may also play a role in restricting population size. The above list will also determine species specific densities, but we know of no study that has successfully integrated all the above variables into a useful quantitative model with predictive power for any habitat-type in North America.

One goal of population ecology is to obtain a list of the prime, but specific, environmental variables that influence changes in population density. To note that temperature-moisture regimes are important does little beyond focusing

attention on particular kinds, or sets, of variables to be measured. Once these variables have been identified, it is necessary to measure and manipulate them in a way that has meaningful application to the specific animal under study. Predictive models will be most easily constructed for species that have conspicuous, easily measured resource needs. Such is the case with snags and secondary cavity nesting birds. These birds nest in natural cavities or those excavated by woodpeckers and thus are limited by the number of suitable cavities (Balda 1975; von Haartman 1957; Zeleny 1972). One must be cautious, however, in attempting to search for a single factor that influences population density. Secondary cavity nesters have complex resource needs and no single factor should have overwhelming predictive value.

The objectives of this study were:

1. To identify environmental variables (weather and habitat) that affect the densities of secondary cavity nesters in ponderosa pine forests.
2. To develop species specific, and guild models that explain and predict population fluctuations of secondary cavity nesters in ponderosa pine forest.
3. To test the accuracy of the predictive models to determine how robust they are.

METHODS AND DATA BASE

In order to construct realistic models that have accurate predictive power, two important factors must be considered. First, if the model is to have predictive value for a given habitat-type, then it is important that data be gathered from a number of stands that are representative of the variation that exists in this habitat-type. Second, if population densities vary between years

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²Russell P. Balda is Professor of Biology, Northern Arizona University; William S. Gaud is Associate Professor of Biology, Northern Arizona University; Jeffrey D. Brawn is Research Associate, Northern Arizona University, Flagstaff, Arizona.

but vegetation does not then data must be gathered over a number of years in order to sample extreme between year variation. Weather may be influential in these variations and should be monitored at the same time (Fretwell 1972).

Some of the data used to construct the models presented herein were first published by Cunningham et al. (1980) and Szaro and Balda (1979). Additional climatic and vegetation variables have been added.

Bird densities in the ponderosa pine forest were obtained using the spot-map method on eight different study plots between 1973 and 1978 (table 1). A total of 21 breeding bird years were used to construct the model. Thus, the data base is broad (eight study plots) and has depth (two to four years per plot).

Table 1.--Study sites used to build and test a model of secondary cavity nesters in the ponderosa pine forest

Year	Study Sites							
	PNA	WS 8	WS 13	WS 14	WS 17	GF	RP	MT
1973			X	X	X			
1974		X	X	X	X			
1975	X	X	X	X	X			
1976	X	X		X				
1977						X	X	X
1978						X	X	X
1979		*	*		*			
1980		*	*		*			

X Data used to build model

* Data used to test model

Weather data were gathered from six different sites, all within three km of a given study plot. Twenty-two different independent weather variables were calculated but only 11 were used as the others were linear combinations of those chosen for inclusion (table 2). Six variables measured precipitation and five measured temperature. Weather data were collected each year of censusing, and divided into periods of the year that were considered relevant to the birds.

Table 2.--Weather variables used in model construction

Variable	Inclusive Dates
Precipitation	25 Mar. - 2 June
Precipitation	(P)* 8 Oct. - 2 Dec.
Precipitation	8 Apr. - 2 June
Snow	30 July - 18 Nov.
Snow	(P) 19 Nov. - 7 Apr.
Rain	8 Apr. - 2 June
Degree Days	(P) 1 Jan. - 25 Mar.
Degree Days	1 Jan. - 2 June
x High Temp.	30 July - 18 Nov.
x Low Temp.	30 July - 18 Nov.
x High Temp.	(P) 19 Nov. - 7 Apr.

* Previous to breeding season

Vegetation structure, including absolute densities and foliage volumes were measured on all study plots using the point quarter methods (Cotton and Curtis 1956) and analyzed using the procedures described by Szaro and Balda (1979). Originally eleven different variables were calculated but only seven were included in the model building procedures. These variations were: 1. Total foliage volume for all strata; 2. Sapling volume; 3. Trunk volume; 4. Total oak foliage volume; 5. Oak importance value; 6. Snag density; 7. Absolute density of all trees.

The regression analysis began with an examination of data from eight study plots during the six years. The BMDP statistical package (Dixon and Brown 1979) was used to identify the best set of regression equations for explaining the variability in densities of secondary cavity nesters. The equations in the best set differed by very small amounts in their R-square values but each contained a different combination of independent variables that could be used to predict bird densities.

Information gathered in 1979 and 1980 (table 1), on three study plots subsequent to initial regression analysis, was used as a test of the predictive validity of the models. Using the regression model from the initial analysis, confidence intervals at the new values of vegetative and climatic factors from 1979 and 1980 were calculated (Draper and Smith 1966). The actual densities of the birds observed during the test census were then compared with the predicted densities and confidence intervals. The best model was considered that one which explained a large amount of the variability in bird densities from 1973-1978, and also predicted well the subsequent densities observed in later years. The SPSS statistical package (Hull and Nie 1981) was used to examine the residuals of the best model.

In northern Arizona's ponderosa pine, secondary cavity nesters make up between 40 and 55% of the entire breeding bird community, and about 33% of the breeding species. As snag densities decline, there is a concomitant decline in the proportion of the total breeding bird community contributed by secondary cavity nesters but not a noticeable decline in breeding species (Balda 1975, Cunningham et al. 1980).

Cunningham et al. (1980) found a significant positive regression model for secondary cavity nesters (as a group) in ponderosa pine forests. Their regression model used three vegetation variables: snag density; non-ponderosa pine foliage volume; ponderosa pine foliage volume. For the same eight areas used in this analysis, 76% of the variability in bird densities were explained by these three independent variables and snag density explained more than half of this variability. They were, however, not able to obtain statistically significant models for the individual species. Snag densities varied from 4 to 208 on the eight plots. Birds preferred tall snags with diameters of 50 to 90 cm. Of the five common secondary cavity nesters, four (Violet-green Swallow

Table 3.--Multiple regression model for Violet-green Swallow and results of testing the model.

Density = 4.22 - 3.14(DISPL) + 0.06(SNAG) + 0.004(FVTOT)		
Observed	Predicted	W/In Confid. Interval?
17.50	10.51	Yes
5.00	9.23	Yes
7.50	5.12	Yes
2.50	3.84	Yes
0.00	-7.34	Yes
0.00	-4.36	Yes
R ² =0.89		
p < 0.0001		

Tachycineta thalassina, Pygmy Nuthatch *Sitta pygmaea*, Western Bluebird *Sialia mexicana* and Mountain Chickadee *Parus gambeli*) placed the majority of their nests in snags whereas the White-breasted Nuthatch *Sitta carolinensis* placed most of its nests in live trees.

In order of increasing sensitivity the common breeding secondary cavity nesters fall into four groups. The White-breasted Nuthatch places most of its nests in live trees and is, therefore, insensitive to snag removal. At low snag densities Western Bluebirds are known to utilize live oaks. Mountain Chickadees and Pygmy Nuthatches track snag density closely but will switch to other nest sites at low snag densities. The most sensitive species is the Violet-green Swallow which nests only in snags (Cunningham et al. 1980). Obviously, we can predict that the more sensitive a species is to snag density the better the model will be if snag density was properly assessed.

RESULTS

Violet-green Swallow

This species is a summer resident and arrives in the ponderosa pine forest in early April. Through the course of this study its density varied from zero to 45 pairs per 40 ha reaching highest densities on plots least disturbed by timber removal. Where snags are clumped this species has a tendency to be colonial. This species is an aerial feeder and obtains insects on the wing. It often uses snags for perch sites.

The selected multiple regression model contained one weather and two vegetation variables. Low mean temperature during dispersal, snag density, and total foliage volume combined to explain 89% of the variability in the year to year fluctuation in breeding populations. Densities from all six plot-years used to test the model fell within the confidence intervals (table 3).

Pygmy Nuthatch

This permanent resident species is one of the most common and widespread breeding species in the ponderosa pine forest. Through the course of this study, this species had densities ranging from one to 42 pairs per 40 ha, reaching highest densities on undisturbed plots. This species often has more than two birds attending nestling young. It also roosts communally in fall, winter, and spring, in cavities in snags. It obtains the majority of its insects by gleaning them from nettle clusters.

The selected multiple regression model contained three habitat variables, all indicative of old growth forest. Total foliage volume, trunk volume, and snag density combined explained 85% of the variation in population density. This model correctly predicted this species density in all six plot-years (table 4).

Mountain Chickadee

This insectivorous, permanent resident species is typical of ponderosa pine and mixed coniferous

Table 4.--Multiple regression model of Pygmy Nuthatch and results of testing the model.

Density = 8.78 + 0.0004(FVTOT) - 0.82(TRNK) + 0.10(SNAG)		
Observed	Predicted	W/In Confid. Interval?
23.70	15.78	Yes
15.00	15.78	Yes
17.50	12.38	Yes
22.50	12.38	Yes
8.70	-0.87	Yes
0.00	-0.87	Yes
R ² =0.85		
p < 0.0001		

Table 5.--Multiple regression model for Mountain Chickadee and results of testing the model.

Density = 24.07 + 0.06(SNAG) - 0.81(TRNK) - 0.28(IVOAK)		
Observed	Predicted	W/In Confid. Interval?
5.00	6.31	Yes
0.00	6.31	Yes
7.50	7.08	Yes
1.20	7.08	Yes
0.00	-0.35	Yes
0.00	-0.35	Yes

R²=0.77
p < 0.0001

forest. Its density ranged from one to 26 pairs per 40 ha during this study. The bird forages by gleaning insects from nettles, twigs, and small branches. This species becomes very secretive during the breeding season.

The three variables that contributed to the statistically significant multiple regression model were snag density, trunk volume, and importance value of oak. These variables accounted for 77% of the variation in breeding density of this species. This model correctly predicted chickadee density in each of six years (table 5).

Western Bluebird

This summer resident, insectivorous species arrives in the ponderosa pine forest before snow melt occurs. In mild winters it may spend its time in the pine forest, roosting in cavities. This species feeds on insects that it hawks off or near the ground. During this study bluebird densities varied from five to 26 pairs.

The significant multiple regression model contained one weather and two habitat variables. Surprisingly, winter mean high temperatures were positively correlated with summer breeding density. Snag density and trunk volume were the two habitat variables in the selected model. Together, these three variables explain 71% of the fluctuation in breeding bird density for this species. Five of six test sets of data fell within the confidence interval (table 6).

Table 6.--Multiple regression model for Western Bluebird and results of testing the model.

Density = 5.80 + 2.5(WINH) + 0.07(SNAG) - 1.14(TRNK)		
Observed	Predicted	W/In Confid. Interval?
0.00	2.46	Yes
0.00	9.00	Yes
10.00	4.44	Yes
10.00	10.98	Yes
15.20	0.60	No
11.00	5.60	Yes

R²=0.71
p < 0.0001

White-breasted Nuthatch

This permanent resident secondary cavity nester prefers to nest in cavities in live pines and oaks. This catholic species occurs in most forests and woodlands in the U.S. It is a trunk and branch gleaner. During this study this nuthatch varied in density far less than the four above-mentioned species, varying only between six and 12 pairs per 40 ha.

The selected model for the White-breasted Nuthatch explained only 50% of the fluctuation in breeding population and contained only weather variables. These were: precipitation in the form of snow during dispersal; mean low temperature during dispersal; mean high temperature during dispersal. These latter two variables had sign changes indicating low temperature had a negative affect and high temperature a positive one on breeding bird density the next year. All six years used to test the model fell within the confidence interval (table 7).

Total Secondary Cavity Nesters

If suitable cavities remain at the same level between years and interspecific interference competition is occurring, then total population density of the secondary cavity nesters should remain stable between years. This will occur because of reciprocal density changes. For every increase by one species there should be a corresponding decrease by one or more of the other species. Use

Table 7.--Multiple regression model for White-breasted Nuthatch and results of the model.

Density = 11.33 + 1.09(DISPS) - 0.63(DISPL) + 0.95(DISPH)		
Observed	Predicted	W/In Confid. Interval?
10.00	5.74	Yes
6.20	7.48	Yes
10.00	5.74	Yes
10.00	7.48	Yes
4.30	7.09	Yes
3.20	5.38	Yes
R ² =0.50		
p < 0.0076		

of partial correlation coefficients between all possible subsets of the species revealed, however, that such was not the case (Balda and Gaud MS), in fact most correlation coefficients were positive. This indicates that most, if not all species increase or decrease independently of one another.

Because of this finding, we felt justified in attempting to construct a model for the total density of secondary cavity nesters. The statistically significant model we chose contained three habitat variables: trunk volume, importance value of oak, and snag density, and these three explained 85% of the variability in total breeding bird density. When testing this model all six plot-years fell within the confidence interval (table 8).

DISCUSSION

Snags have most likely been a conspicuous and stable component of the ponderosa pine forest for thousands of years because they result from natural processes such as senility, wind, fire, insect damage, and lightning. It is, therefore, predictable that some animals would come to rely on them for their survival and reproduction. One such specialized group is the secondary cavity nesters, which have come to rely on standing, dead trees that have accumulated woodpecker holes and lightning strikes, through time, for nesting and roosting sites. This reliance has been negated because old, standing, dead trees have not been properly placed in management schemes and plans. In fact, snags have been persecuted for so many years, it

is difficult to get a realistic assessment of their role in managed forests. Snag removal policies plus fire suppression practices have left us little to work with in modern times. We have few, if any, natural or control areas to use as standards for comparison. Thus, our data, and the conclusions we draw from them may be suspect. Yet, it is better to provide the manager with the best information available than to provide no information.

Comparing across species, a total of 18 variables could have had significant predictive value in the multiple regression models described above. Yet, only four of seven habitat variables and four of 11 independent weather variables were entered in models that gave the highest predictive accuracy. All eight variables entered into the multiple regression models with the same sign regardless of the species specific model. Thus, this taxonomically diverse group of species may be limited by the same, or similar, environmental variables. Vegetation variables made significant contributions to the models in 13 of 18 possible cases and weather variables made significant contributions in the remaining five instances.

The species that used snags least for nest sites, the White-breasted Nuthatch, was unique in that all variables in the statistically significant model were climatic ones and two were unique to the species. Why autumn snow combined with high autumn temperatures should have a positive impact on next years breeding population of White-breasted Nuthatches is not immediately obvious but fall insect populations may respond positively

Table 8.--Multiple regression model for total density of secondary cavity nesters and results of testing the model.

Density = 157.07 - 4.25(TRNK) - 1.65(IVOAK) + 0.27(SNAG)		
Observed	Predicted	W/In Confid. Interval?
56.20	54.27	Yes
26.20	54.27	Yes
52.50	59.64	Yes
46.20	59.64	Yes
28.20	19.78	Yes
14.20	19.78	Yes
R ² =0.85		
p < 0.0001		

to warm, wet snow. This may have a beneficial affect on the survivorship of young and/or adult White-breasted Nuthatches. Also, it is of interest to note that the species least sensitive to declines in snag densities had all weather related variables in the most predictive model, and these variables could account for the least variance for any of the five species.

Violet-green Swallow populations were also influenced by weather, specifically, mean low temperatures during the fall dispersal period. Low autumn temperatures may cause a precipitous drop in flying insects. The lack of food during fall and early winter is known to be particularly devastating to young birds of the year (Lack 1954) and this heavy mortality may affect population size the next year.

The multiple regression model for the Western Bluebird contains an interesting weather factor, mean high temperature during the winter, which had a positive affect on density. Two possible explanations are immediately obvious but remain speculative. First, high temperatures in winter may be conducive to ground insects as survival of pupae may be better in mild winters. Thus, food supply for bluebirds may be higher in spring. Also, ground insects may hatch out earlier after mild winters. A second explanation is more direct, as in mild winters some bluebirds may spend the winter in the pine forests. These birds may gain priority rights to certain nest sites and spring returning birds may then take less suitable sites, especially if insect densities are high.

Vegetation variables were far more prevalent in the models than weather variables, with snags appearing in five of six models. Thus, this variable is the single most important factor in determining density of most of the secondary cavity nesters. Because White-breasted Nuthatches do not prefer snags for nest sites it is not surprising this variable did not appear in its model.

In addition to snag density, total foliage volume appeared twice, and in both models (Pygmy Nuthatch, Violet-green Swallow) it was positively correlated with bird density. Foliage volume was also important in the preliminary models constructed by Cunningham et al. (1980). Earlier, Balda (1969) found pine foliage volume to be limiting for Pygmy Nuthatches in pine forests in southeastern Arizona.

The other two variables, trunk volume and importance value (relative density + relative frequency + relative dominance) of oak appeared in models five times. These two consistently had a negative influence on population size.

Trunk volume had a simple correlation of 0.51 with total foliage volume, yet entered the regression models with the opposite sign from foliage volume. It appears that secondary cavity nesters prefer a situation where foliage volume is high but trunk volume is low. This situation would occur in forests in which old "yellow pines" were relatively sparsely and well spaced, and trees of

intermediate age were common. Thus, heterogeneous stands seem to be favored over homogeneous ones. Szaro and Balda (1979) found bird populations to be lower in a stand that had not been cut for 60 years than in stands that had received moderate silvicultural treatment. It would appear then, that foliage volume associated with old "yellow pines" is not as productive in terms of providing resources to the secondary cavity nesters as is the foliage of more intermediate-aged trees. Yet, it is the older trees that eventually become snags.

It is possible that in this case the birds are telling us something about the primeval state of the ponderosa pine forest? One scenario proposed by Cooper (1960) stated that large stands of ponderosa pine forests were of even age due to the effects of wild fire, i.e. old senescent forests eventually burned down to be replaced by young, even-aged trees. Young seedlings are fire resistant and can withstand the cool fires that burn through these stands. If such was the case, then secondary cavity nesters would have been limited to the edges between old senescent forests and middle-aged vigorous ones, each distinctly separate in their distribution. In many regards, however, these species do not respond as ecotone or edge species but more like forest interior ones. Thus, we suggest the ponderosa pine forest was heterogeneous, in regards to age of stand, in the primeval state, with snags scattered throughout the forest.

The role of oaks, primarily Gambel's oak, remains as an enigma. In two cases the importance value of oak appeared as having a negative influence on the population of secondary cavity nesters. This influence may either be a direct or indirect one. In fact, for White-breasted Nuthatches the simple correlation should be a positive one because this species is known to nest in oaks. Such is not the case as this correlation coefficient has no statistically significant influence on White-breasted Nuthatch breeding bird densities.

Importance value of oak, however, may indicate site quality for ponderosa pine as the simple correlation coefficient between this variable and total foliage volume was -0.81. Thus, where oaks are prevalent ponderosa pine may be restricted in growth and vigor.

As predicted, the models that explained the most variance in population size were generated for the species most sensitive to a change in snag numbers. The model for the Violet-green Swallow (most sensitive) explained 89% of the fluctuation in population size whereas the model for the White-breasted Nuthatch (least sensitive) explained only 50% of this variance. The intermediate species were arranged as predicted.

MANAGEMENT IMPLICATIONS

1. Snag management must be integrated into an overall management plan for the ponderosa pine forests that includes some measure of foliage volume that can supply other resources such as

thermal cover, predator cover, and food resources.

2. Heterogeneous stands containing a mixture of old "yellow pines" and vigorous trees of intermediate age appear to be the ideal habitat for this select group of species.

3. Densities of secondary cavity nesters will be influenced by weather as well as vegetation characteristics of the forest. However, stand quality and vigor may mediate some weather conditions and make areas more hospitable to the birds.

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Challenges of Snag Management¹

Gregory A. Goodwin²
and
Russell P. Balda³

Abstract. -- Snags provide needed resources for 85 species of North American birds, numerous plants, invertebrates, reptiles, amphibians and mammals. Snag habitat research and management needs can be broken down into six general categories: 1) establishing realistic economic values for nongame wildlife and habitat improvements; 2) finding answers to questions raised by the National Forest Management Act; 3) understanding the role of snag-dependent birds and mammals in forest ecosystems; 4) developing methods to create snag habitat and improve snag habitat for selected species; 5) learning to integrate snag management and fuelwood management; 6) pursuing intensive public information and law enforcement programs. These areas of study are needed to provide managers with information for making management decisions.

INTRODUCTION

Snags provide needed resources for 85 species of North American birds, (Scott et al. 1977) numerous plants, invertebrates, reptiles, amphibians, and mammals. It is generally assumed and supported by empirical findings that a direct relationship exists between the number of snags present and population levels of snag-dependent wildlife species occupying an area. Many species of snag-dependent birds have declined because of habitat reduction. The ivory-billed and redcockaded woodpeckers are currently on the endangered list. The wood duck now depends heavily on artificial nest boxes for its continued survival. European forests, which are intensively managed, support no snags, and consequently artificial means must be used to sustain many species of wildlife.

Each forest community supports a distinct group of snag-dependent wildlife species which have evolved through time to fill a particular role in the ecosystem. Each wildlife species has distinct requirements for diameter, age, height, and species of snag it uses. This

selection has adaptive value for each species in terms of survival and reproduction, yet in many cases we may not be able to determine these requirements because management practices have already removed the optimum, and species may be existing under suboptimal conditions.

In many forested areas, past management activities have reduced and even eliminated the potential of forests to produce and retain snags. Dead and dying trees which would have become snags were routinely removed during sanitation cuts. Existing snags were removed for safety reasons and for many years were methodically cut down as fire hazards. Shorter rotation intervals have eliminated older stands resulting in a reduced potential to produce large diameter snags.

Only during the past 10 years have land managers begun to recognize snag management problems and the inherent values of snags. Research conducted on snag dynamics and habitat requirements of snag-dependent wildlife has contributed to the implementation of snag management policies by Federal land management agencies. However, this is only the beginning of management of the snag resource. Six general categories of research and management needs are necessary to provide resource managers with the kind of information necessary for making wise snag management decisions.

ECONOMIC VALUES

As managers and researchers, we are still concerned about establishing, and more importantly,

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²Wildlife Biologist, USDA Forest Service, Coconino National Forest, 2323 East Greenlaw Lane, Flagstaff, Arizona 86001.

³Professor of Biology, Department of Biological Sciences, Northern Arizona University, Flagstaff, Arizona 86011.

communicating realistic economic values for wildlife, especially nongame wildlife. Most people will agree that wildlife outputs of the typical forest possess value, but great differences of opinion arise as to the relative amounts of such values. Some approaches to evaluate wildlife values have been made, yet a large measure of intangibility always surrounds many of these values (Clawson 1975). This puts managers at a decided disadvantage because other forest resources have easily defined and measured economic values. Measuring wildlife outputs, assigning those outputs a value, and communicating those values to decision makers are major problems facing many agencies. A process is also needed to assign values to habitat improvement work done for wildlife. This type of information will facilitate management decisions, especially where there are conflicts between wildlife and other resources. This approach may not be the best way to compare wildlife with other resources because of the subjective nature of assigning dollar amounts to most wildlife. A better approach may be to start with the basic premise that all species are integral to ecosystem functions. Using recreation cash values, as most agencies do, ignores that wildlife enhances the quality of human life. It also ignores the biological value wildlife has as part of an integrated ecosystem. Recreational uses of wildlife are easily defined but difficult to measure.

NATIONAL FOREST MANAGEMENT ACT

The National Forest Management Act of 1976 poses several questions concerning wildlife that must be dealt with in Forest Service land management plans. Answers must be found for questions such as: what are the best indicator species for snags in different forest types; what are the minimum habitat needs for snag-dependent wildlife species; how can snag habitat be provided over time in conjunction with intensive timber management; how should snags be distributed; how should snag-dependent wildlife be monitored and what are stable densities for snag-dependent species. The requirements of this Act present substantial management problems and provide major challenges for research.

ROLES OF SNAG-DEPENDENT WILDLIFE

The role of insectivorous, snag-dependent birds in forest ecosystems is a major question that has received some attention by researchers. Of particular interest is understanding the relationship of snag-dependent birds to insect population dynamics. Many early works tended to overstate the case and used simplistic interpretations of birds controlling insect populations (Thomas 1979). Definitive data is needed to illustrate the role that snag-dependent birds and insectivorous bats play in holding insect populations at endemic levels or exerting some control during early stages of outbreaks.

Understanding this relationship will help give economic consideration to the basic functional characteristics of the ecosystem in the decision making process of land management agencies. Since snag-dependent birds and mammals make up a large proportion of the insectivorous, forest dwelling wildlife population, it is important to adequately reflect the relationship to insect populations with realistic economic and biologic values.

CREATING AND IMPROVING SNAG HABITAT

Cost effective methods for creating snag habitat and/or improving habitat for selected snag dependent species are becoming increasingly important. In the past, managers have been concerned only with preserving existing snags. Finding ways to improve habitat for various wildlife species or groups of species and how to create snag habitat from live trees present research and management with important challenges. Answers to these questions will provide valuable management tools.

We may be faced with providing artificial resources such as nest boxes, as a result of continuing habitat reduction from increasing demand for wood products. This alternative may not be the most appealing, however, it may be our only recourse near urban areas or other areas heavily impacted by timber salvage operations or fuelwood use. While nest boxes may be a valuable management tool for some problems or problem areas, boxes cannot be considered a total substitute for snags. But the use of artificial nesting structures is certainly deserving of additional research. We need the baseline data now so applications can be made when critical situations arise.

Meeting snag requirements over time is a critical question facing resource managers today. As timber management intensifies, there is a tendency to eliminate large trees that could become snags. In addition, existing snags will be lost through natural processes, and fuelwood activities. This will reduce snag recruitment and result in substantial reductions in snag densities. We need management, policies and practices that will ensure a sufficient number of quality snags to provide for long-term survival and reproduction of snag-dependent wildlife species. A major challenge facing all of us is to get consideration for wildlife habitat firmly ingrained into timber planning and management.

ENERGY DEMANDS

The increasing demand for fuelwood poses a particular threat to snag-dependent wildlife species. Wood is becoming increasingly attractive as an alternative energy source as the cost of home heating increases. Fuelwood demand is increasing as populations increase. This is already presenting critical management problems in some areas due to illegal fuelwood harvesting. Fuelwood harvest was largely concentrated around urban areas in the past but with increased demand,

harvesting has increased in distant less accessible areas. The projected increases in fuelwood demand present a challenge that we must meet while still providing habitat for snag-dependent wildlife species.

Land managers must begin to carefully analyze fuelwood harvest alternatives based on a clear understanding of the impacts on wildlife and the long-term impacts on the forest. Snag management and fuelwood management must be integrated into timber management programs if we are to ensure proper management of these two resources.

PUBLIC EDUCATION

Illegal fuelwood harvest is a major management problem in many areas. Most people think snags have no biological value. They can see only the value of the wood for burning in fireplaces and woodstoves. We as researchers and managers must convey to the public, including private landowners, the importance of snags to wildlife and to forested lands. We must change public attitudes toward snag management. Although changing public attitudes through the educational process is slow, its pursuit is none-the-less important because historically good forest management meant removing snags. This is an important challenge that we must pursue aggressively.

Smokey the Bear has been an extremely effective public education tool in Forest Service fire prevention programs. Perhaps the Forest Service should add a third mascot to its public education team of Smokey and Woodsy Owl. What better candidate for the job than a nationally recognized figure like Woody Woodpecker?

Public education is a difficult process made even more difficult by the fact that, before completing high school, most of our personal traits have already been formed (Hamilton 1982). There is ample evidence that our education system has thus far failed to develop a conservation ethic or understanding (Hobart 1972). We must make wildlife and other natural resource subjects a part of the K-12 curriculum. Natural resource material is being developed and used in some states (Hamilton 1982). We need to take a more active role in dissemination of this material. Long-range education programs must build solid foundations for understanding resource management. An awareness by the public of man's dependence upon, and responsibility for, natural ecosystems and an understanding of the values of wildlife are critical to long-term resource management and conservation. Conservation education must build an ethical underpinning for land economics and a universal curiosity to understand the land mechanism. Conservation may then follow (Leopold 1953).

Biologists too need to be better educated in ecosystem management. Most biologists are well-versed in the biological details of animals,

and usually in depth only about a species or small group of animals. But we often lack knowledge of habitat requirements related to populations of wildlife (Cutler 1982) and the role these populations play in an integrated ecosystem.

Along with public education goes an increased need for enacting and enforcing of fuelwood laws. Law enforcement is a basic management tool. However, it has, in many ways, been neglected in forest management by land management agencies. We need to recognize fuelwood law enforcement problems and take appropriate action to allocate money and people to carry out enforcement programs. History has repeatedly shown us that public morality and ethics cannot be legislated. However, enacting realistic state fuelwood laws, establishing uniform fuelwood policies, and strong enforcement of fuelwood laws is critical to the continued existence of snags on many acres of forested lands. Open and continuous communications between enforcement and management agencies, and research agencies will contribute significantly to our ultimate success.

CONCLUSIONS

In many forested areas, timber management, fuelwood activities, and fire prevention and suppression activities are making snags a persecuted and endangered wildlife habitat.

"The vulnerability of snags makes snag-dependent wildlife equally vulnerable. If snag-dependent wildlife species are to remain as part of the managed forest, forest managers must provide the necessary habitat." (Thomas 1979)

Although there are differences in detail, most of us can agree on a number of basic principles of snag management.

1. Manage for the total ecosystem of which snags are an integral part.
2. Through research, establish a basic understanding of the ecological, social and economic aspects, not only of snag-dependent wildlife, but of all wildlife.
3. As professional resource managers and researchers work towards establishment of conservation and resource education programs.
4. Make wildlife policy decisions based on public interest and sound ecological principles, not just on special interests.
5. And finally, "spare that old dead tree," or, "what we need around here is a little more dead wood."

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These proceedings include 41 papers focusing attention on the need to integrate management of snags -- dead or deteriorating trees critical to needs of cavity-dependent wildlife -- with other resource uses and demands. Sessions concentrated on management, habitat and species requirements, and monitoring and modeling.

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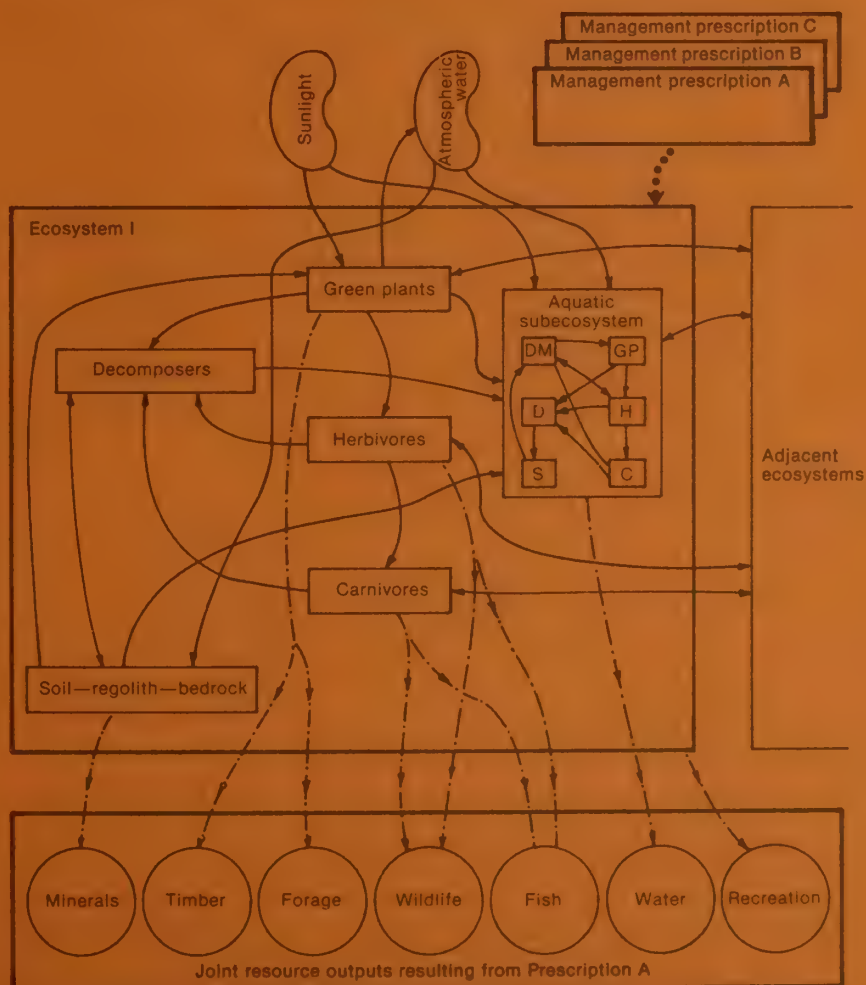
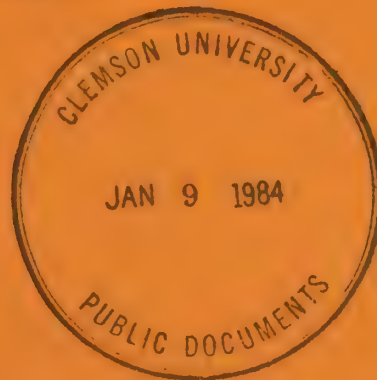
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Forest and Range
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Fort Collins,
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Prediction of Wildlife and Fish Resources for National Assessments and Appraisals

Clifford L. Hawkes
David E. Chalk
Thomas W. Hoekstra
Curtis H. Flather



Abstract

The ecological analysis techniques discussed are useful in models to assess the renewable resources of the nation's forests, rangelands, agricultural lands, and associated waters. Outputs of the techniques are habitat quality, habitat quantity, population occurrence, population quantities, population age structure, population size structure, and population sex structure. Types of analytical techniques included are expert opinion, habitat quality indexes, regression analyses, multivariate analyses, pattern recognition procedure with Bayesian statistics, life table analyses, Leslie matrix analyses, and models of harvest, population dynamics, predator-prey, systems ecology, linear programming, linear equations, difference equations, and differential equations.

Prediction of Wildlife and Fish Resources for National Assessments and Appraisals

Clifford L. Hawkes,¹ Research Aquatic Biologist

David E. Chalk,² Biologist

Thomas W. Hoekstra,¹ Research Wildlife Biologist

Curtis H. Flather,¹ Biological Technician

¹USDA Forest Service, Rocky Mountain Forest and Range Experiment Station. Headquarters is in Fort Collins, in cooperation with Colorado State University.

²USDA Soil Conservation Service, on assignment to the Rocky Mountain Forest and Range Experiment Station.

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Prediction of Wildlife and Fish Resources for National Assessments and Appraisals

Clifford L. Hawkes, David E. Chalk, Thomas W. Hoekstra,
and Curtis H. Flather

MANAGEMENT IMPLICATIONS

This overview of ecological analysis techniques for predicting—as contrasted with directly inventorying—wildlife and fish resources provides state, regional, and national analysts with a better understanding of the techniques available, for use in national assessments and appraisals, to predict wildlife and fish population occurrence, quantities, harvest quantities, and structure.

Although the techniques for predicting terrestrial wildlife are quite useful, they need to be made more biologically and ecologically complete and accurate. Many techniques use habitat variables to arrive at a habitat quality or suitability rating, usually expressed as an index of the habitat capability to produce wildlife. In most cases, models predict potential rather than actual population occurrence, quantity, or structure. Techniques that provide estimates of population levels are for relatively small areas and have rarely been tested in the field.

Techniques for predicting aquatic wildlife and fish habitat quality and population or harvest quantities in ponds, lakes, and oceans, while deficient because they require important biological and ecological assumptions that can not be entirely substantiated, are among the most mathematically rigorous analysis techniques. Many of the models to predict harvest quantities also provide estimates of sex ratios and numbers, age structure and numbers, or size structure and numbers. A few techniques for predicting habitat quality and population quantities in streams and rivers have been developed recently. Techniques to predict aspects of aquatic resources over time are rare. Most techniques are applicable only to small, site specific situations and to a single species rather than guilds; communities; or all the species, as a group, of entire ecosystems. Also, techniques exist only for a limited number of species. There presently are no techniques for predicting population occurrence only.

The accuracy of most of the techniques for predicting terrestrial and aquatic wildlife and fish is not discussed in this paper because there are no established standards by which to evaluate their accuracy.

The slow development of ecological analysis techniques for predicting wildlife and fish resources reflects the relatively incomplete understanding of ecosystem structure and function and of habitat relationships and intraspecies and interspecies interactions. Also, the relationship between population structure and habitat

variables are poorly understood in predicting population quantities. Many models have not been adequately tested for their ability to predict existing or future wildlife and fish resources. Recently, increases in research into ecosystem structure and function, and community structure and function, may lead to improved techniques for predicting wildlife and fish resources.

INTRODUCTION

Periodic national assessments of renewable natural resources are required by the Forest and Rangeland Renewable Resources Planning Act of 1974 (RPA)³ as amended by the National Forest Management Act of 1976 (NFMA).⁴ The Soil and Water Resources Conservation Act of 1977 (RCA)⁵ requires appraisals of the soil, water, and related resources. The Federal Land Policy and Management Act of 1976 (FLPMA)⁶ requires inventories and documentation for development of policies and management of the nation's federal lands. Assessments are to be an integral part of land management planning and natural resource management processes within the United States Department of Agriculture Forest Service, National Forest System. These processes are guided by regulations which state that "Fish and wildlife habitat shall be managed to maintain viable populations of existing native and desired nonnative vertebrate species in the planning area."⁷

The assessments and appraisals of fish and wildlife, mandated by the various laws and regulations require an analysis of present and anticipated uses, demand for and supply of the multiple renewable resources, and price relationship trends into the future. They also require an evaluation of various opportunities (e.g., application of alternative management prescriptions) for improving the yield of tangible and intangible goods and services from these multiple resources, together with estimates of investment costs and direct and indirect returns to the federal government.

Although the past 50 years of wildlife and fish management have involved decreasing emphasis on a

³Public Law 93-378. *United States Statutes at Large*. Volume 88, p. 476 (P. L. No. 93-378, 88 Stat. 476).

⁴P. L. No. 94-588, 90 Stat. 2949.

⁵P. L. No. 95-192, 91 Stat. 1407.

⁶P. L. No. 94-579, 90 Stat. 2743.

⁷*Federal Register*. Volume 47, p. 43048 [47 Fed. Reg. 43048 (1982)] [Section of the Code of Federal Regulations affected is Title 36, Part 219.19 (36 C.F.R. 219.19)]

description of the resources and an increasing emphasis on cause and effect predictions of change, wildlife and fish management has been slow to use new resource planning processes. Because wildlife and fish resources typically are not priced commodities, they may be considered external to the commodity planning process and treated as legally or socially imposed constraints (e.g., protection of threatened and endangered species). However, techniques that have been an integral part of the planning process in business and industry, such as trade-off analysis and optimization, are now being tested and required in renewable resource planning conducted by government agencies. This will help agency planners to better anticipate future capabilities and uses of natural renewable resources and to determine allocations of land, labor, and capital. It will also speed decisionmaking and provide improved planning techniques to reduce resource deficiencies and conflicts.

Before managers can effectively use these new techniques, however, current ecological knowledge and methods must be integrated with socioeconomic considerations in the decisionmaking process. This means developing an estimate of the quality and quantity of the resources in the nation's ecosystems over time. It also means developing an understanding of both the economic efficiency and social value of achieving this quality and quantity of the resources. Then the ecological, economic, and social considerations should be integrated to predict probable ecological, economic, and social outcomes under various assumptions about future supply and demand.

RESOURCE PRODUCTS COMPARED WITH ECOSYSTEM COMPONENTS

In a socioeconomic context, resource products are identified, named (e.g., timber, wildlife and fish, water, range), and incorporated into analytical procedures in terms of their perceived importance to humans. Many of the available analytical procedures reviewed in this paper were developed within this socioeconomic context and, in addition, were designed to answer single resource questions. Because such questions are about parts of ecosystems, answers require ecological analyses. However, because these questions are framed in a single resource, socioeconomic context, rather than in an ecosystem context, they deal only with small fractions of ecosystems. These parts usually are not equivalent to the ecosystem components used by ecologists (e.g., primary producers, herbivores, carnivores, decomposers; fig. 1) and are not usually organized in an ecosystem component/process framework (e.g., do not deal directly with energy flow).

Resource assessments that involve multiresource ecosystem components or processes must be designed to (1) predict the simultaneous response of all renewable resources (e.g., wildlife and fish, timber, water, range) to a present or future situation of an ecosystem, and (2) deal with conservation and protection of resources in

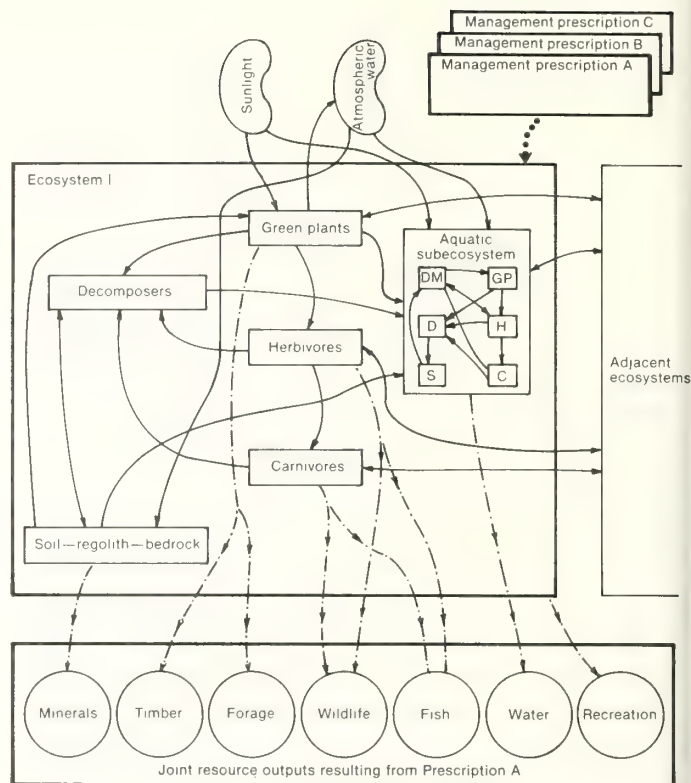


Figure 1.—Depiction of an ecosystem indicating the administration of one alternative management prescription and that a unique set of joint resource outputs result.> application of management prescriptions to ecosystems, —> energy and material (elements) flows resulting from ecological processes, - - -> energy and material (elements) flows resulting from harvest by humans, and recreation use other than harvest of wildlife and fish, DM - dissolved material, D - decomposers, GP - greenplants, H - herbivores, S - substrate, C - carnivores.

order to maintain a sustained, optimum yield of all resources. Such analyses must deal with the stability, resilience, and cycles of ecosystem components/processes. Answers that are developed from within an ecosystem component/process framework must be converted into the terms of socioeconomic resource products (fig. 1).

GENERAL CHARACTERISTICS AND CRITERIA FOR EVALUATION

There are relatively few types of analytical techniques used in estimating the fish and wildlife resources. It is the particular combination of parts, the unique structure, the input variables used, and the degree to which predictions are made over time and at different spatial scales which distinguish the various techniques within a given type of output.

The techniques reviewed here have various limitations. In some cases, the knowledge of ecological requirements is lacking, but there are mathematical procedures for estimating the relationships. In other cases, the ecological relationships are well understood but the mathematics have not been developed to ade

quately express those relationships. In still other cases, knowledge of both the ecological and mathematical relationships is inadequate. Finally, the limitation may be in the existing techniques for collecting the needed data. In these cases, researchers must either develop better ways to measure the variables presently in use, or identify and test new integrator or surrogate variables for which data can be obtained more easily.

Ecological Analysis Techniques

Use of expert opinion is the most basic analytical technique. In this technique, an expert applies his or her knowledge of species-habitat relationships; species-habitat requirement variables; and population quantity, structure, and dynamics variables; to make estimates of wildlife and fish resources.

Some procedures utilize various standard multivariate analyses, such as principal components analysis, discriminant analysis, factor analysis, and cluster analysis.

Habitat quality analysis techniques involve a series of graphs, each with a curve relating quantitative levels of one habitat variable to the optimum for a given species. Each variable is represented in an equation in such a way as to reflect its importance relative to the other variables in the equation. Based on real or proposed situations, numbers (from 0 to 1) were taken from the graphs and placed in the respective expressions of the equation. Solution of the equation provides a number that is the index of habitat quality for a particular species in question.

The technique of pattern recognition analysis, coupled with Bayesian statistics, was first developed in diagnostic medicine. It is a procedure by which a specified group of variables, each with a specified range of values, constitutes a pattern for recognizing that a certain quality and quantity of habitat exists for a species. A certain population quantity of a species can be estimated if the relationship between certain combinations of habitat quality and quantity and population quantities has been determined.

Linear programming is an optimization technique which enables identification of the group of management practices, the intensity or level at which those practices must be applied, and the sequence in which they must be applied to achieve a selected wildlife or fish management goal (Davis 1967).

Depending on the model used, population dynamics models enable the investigator to predict population quantities, structure, and dynamics and harvest or yield. Again, depending on the model, single species and interspecies competitive interactions, predator-prey interactions, and fishing pressure also can be estimated. Mathematical procedures used in the models include differential and integral calculus, difference equations, matrix algebra, and life tables. Input data include population quantities, mortality, natality, and population sex, age, and/or size structure.

Another technique is the use of systems ecology models. These models utilize notation, such as that of

Forrester (1961, 1968), and involve system sources, components, sinks, material or energy flows, information flows, and control gates. The models are designed to simulate the behavior of a small subsystem of an ecosystem or an entire ecosystem from which predictions of the wildlife and fish resource can be made.

Criteria for Evaluating the Ecological Analysis Techniques

The analysis techniques presented in this report are evaluated in terms of the attributes of the input data used and output data produced. The accuracy of most of the predictive techniques is not discussed in this report because there are no established standards by which to evaluate their accuracy. Most of the theoretical predictive formulas have not yet been tested. However, the paper includes a discussion of the factors related to the use and applicability of each technique in the assessment process.

Evaluation criteria considered include features of the input and output data, the subjectivity of the technique in using that input data to derive an output, and the degree to which the technique might fit into an integrated, multisource analysis procedure. A completely integrated approach would include ecological analyses for estimating outputs of all the natural renewable resources simultaneously, analyses of economic costs and social benefits, and analyses that deal with all spatial hierarchical levels. When integrated procedures are discussed here, only natural, multiple resource, ecological analyses are considered.

Output Evaluation Criteria

1. Degree of information provided by the output:
 - a. Habitat quality (suitability).—The potential of a given habitat to support a selected wildlife or fish species (usually expressed as a numerical value or index),
 - b. Species occurrence.—The presence or absence of a selected species of wildlife or fish,
 - c. Population quantities.—The total number or biomass of a selected species per unit of area (includes estimates of either the total population or the portion of the population that can be harvested according to some criteria), and
 - d. Population structure and dynamics.—The sex ratio, age classes, size classes, and mortality and natality rates of a selected species population;
2. Time period over which the technique is applicable; and
3. Geographic scale to which the technique applies.

Input Evaluation Criteria

1. Quantity and quality of information supplied by the inputs:
 - a. Species-habitat requirements variables,

- b. Population quantity variables, and
- c. Population structure and dynamics variables; and
- 2. Availability and objectivity of data:
 - a. Number of variables,
 - b. Variables estimated by expert opinion (expert opinion may provide high-quality data),
 - c. Variables obtained by remote sensing,
 - d. Variables obtained by field inventory, and
 - e. Integrator variables used.

Incorporation of Effects of Management

Except in the techniques that estimate harvest population quantities, management practices, as such, do not enter into the procedures. However, management practices cause changes in one or more of the habitat requirement input variables. Some practices affect populations directly. Therefore, in order to predict the effects of management practices, it is necessary for the analyst to identify the variables affected, and to quantify the amount that a practice would change these variables. This relationship is rarely described in the literature.

A DESCRIPTION AND EVALUATION OF THE ECOLOGICAL ANALYSIS TECHNIQUES

TERRESTRIAL WILDLIFE ANALYSIS TECHNIQUES

The ecological analysis techniques needed to estimate terrestrial wildlife resources in a land management planning context have developed towards three inter-related goals. These are estimation of habitat capability, species occurrence, and population quantity and structure. Some techniques incorporate aspects of all three goals. However, most can be classified into one of these analytical types.

Habitat capability techniques generally develop an index based on an inventory of habitat variables related to the habitat requirements of wildlife species. A species is assumed to occur in habitats that are determined capable of meeting the species requirements. These techniques have found general acceptance for use in mitigation type evaluations.

Species occurrence techniques incorporate known information on species occurrence with an inventory of species habitat variables to develop prediction equations. These equations assume that when habitat conditions are found within the range of those evaluated in developing the model that the species will be present. Tests of this assumption are important but are infrequently carried out. The use of species occurrence techniques in large land area analyses largely depends upon the availability of occurrence or population density data; the latter is more desirable.

The requirements of techniques for predicting wildlife population quantities and structure are the most difficult to meet of those discussed. These techniques incorporate habitat and species population inventories

to develop statistical models. They also include habitat requirements to develop simulation models. The major difficulty in developing and using these techniques is the deficiency in population data. As a consequence, this technique frequently is used to calculate potential populations without the necessary estimates of error.

Habitat Estimation

Habitat has long been used as an output measure in wildlife production analyses, because it is easier to measure than animal populations. In nearly all of the analytical methods discussed here, habitat variables are used to determine a habitat rating; this rating is usually expressed as a quality or suitability index of the habitat's capability to produce wildlife. Early terrestrial wildlife techniques that predicted or calculated habitat quality generally tended to be characterized by subjectivity. As the procedures developed, more emphasis was placed on quantitative methods. The techniques reviewed tended to analyze local, current conditions, and rarely appeared to be applicable at the regional scale of analysis. Analysis of future habitat conditions is possible when associated analytical methods are used to project the habitat variables into the future, and assuming that species habitat relationships remain constant.

Analysis techniques developed by Buckner and Perkins (1974), Hamor (1974), Hawes and Hudson (1976), Whitaker et al. (1976), and Boyce (1977) typify early efforts relying heavily on expert opinion in evaluating habitat suitability.

Buckner and Perkins (1974) attempt to establish a compromise between intensive documentation and visual estimation of wildlife habitat status on industrial forest land. The procedure involves a systematic sample of a timber tract that is stratified by forest stands. Each plot is visited and assigned a numerical rating from 1 (very poor habitat) to 6 (excellent habitat) for each species under consideration. The rating is based solely on the evaluator's knowledge of each wildlife species and his perception of potential limiting factors. An average habitat value index is then calculated for several sample sites within a forest stand. An index value for the entire tract is obtained by summing the weighted average of each stand value. Relative weights are based on the percentage of total acres represented by each stand. Because this method is subjective, no standard species-habitat relationships can be established, resulting in the potential for inconsistent evaluations. It is not possible to update the stand or tract indexes without a new field survey.

Hamor (1974) provides a similar methodology; however, the habitat suitability indexes represent wildlife in general. The technique was developed primarily to help mitigate effects of local water and related resource developments. Again, the quality values are obtained subjectively through the use of tables that: (1) first describe a small set of habitat conditions (e.g., even-aged hardwoods with an open understory and overgrazing by livestock) and, (2) assign a relative index value

ranging from 0-1 for each defined habitat condition. A composite habitat value is obtained by multiplying the relative index by the total acres under evaluation.

Expanding the scope of application to a regional scale, Hawes and Hudson (1976) proposed a method, based on a biophysical landscape classification, that uses an evaluation of each land system's capability to provide the required habitat for selected species. Areas are classified into land forms with associated climax vegetation and soils. The system converts classified inventory data into a suitability rating for a species. Information on species requirements comes from literature and expert opinion. Their method concerns only species that use climax vegetation. The final output is a qualitative habitat suitability rating.

Whitaker et al. (1976) developed models, for species characteristic of the Maryland Piedmont region, that use line charts to establish species-habitat relationships. Each line chart represents a linear scale used to inventory habitat characteristics such as average tree diameter at breast height, percent ground cover of understory, percent herbaceous ground cover, etc. The line charts for each habitat characteristic are translated into a suitability index using a transformation scale that is species specific. A weighted average for an entire habitat type represents the final output.

The DYNAST (Dynamically Analytic Silvicultural Technique) system developed by Boyce (1977) is an attempt to analyze multiple benefits. The habitat evaluation submodels are based on easily inventoried habitat variables (e.g., the distribution of size class and forest openings) which represent the more numerous and complex species-habitat relationships identified for each species. A curvilinear relationship is established for each variable, which relates possible variable values to a habitat index. A mathematical algorithm defined by the model builders is then used to combine the individual variables into a single habitat index.

A more recent implementation of the professional judgment technique in a multiple use context is the Information Management on a Grid Cell System (IMGRID). This system (Davis 1980) enables consideration of wildlife habitat suitability. Calculation of the habitat rating involves species-habitat relationships (as determined by biologists) and seasonal variation in habitat requirements; a weighting procedure is used to express the relative importance of the habitat components. The actual input variables depend on the species under consideration; however, the broad categories examined include food, water, cover, reproductive requirements, special requirements, and interspersions. The mathematical manipulation function of IMGRID is used to sum values to arrive at a composite habitat rating. The evaluation delineates relatively homogeneous areas each of which has specific capabilities to provide the requirements of a particular species.

In an attempt to alleviate the lack of concurrence among subjective evaluators, Thomas et al. (1976) developed extensive guidelines for evaluating habitat quality. The concept they used in developing the guidelines came from Haapanen (1965). Outputs from these guidelines are wildlife species richness, plant species

richness, diversity, and stability. The guidelines were based on several assumptions:

1. Wildlife production is generally a by-product of management for other resources.
2. The ability to predict wildlife population quantities, over time, is the weakest link in an assessment.
3. Lack of knowledge is less of a problem than lack of a conceptual framework for:
 - a. consideration of all terrestrial vertebrates,
 - b. retention of the ability to emphasize a particular species, and
 - c. identification of specific habitats requiring special attention.

The guidelines developed by Thomas et al. (1976) represent a set of relationships between habitat variables and species response. The response, however, is not equivalent to predictions of habitat quality, species occurrence, population quantities, sex structure, or age structure. There are three parts to the guidelines:

1. The relationship of all vertebrates to forest communities and successional stages (four levels of information are provided):
 - a. response of all vertebrates, condensed into 16 life forms, to community and successional stage of the habitat;
 - b. response of individual species within the life form;
 - c. detailed biological data on each species; and
 - d. guidance to additional literature on each species.
2. Guidance on methods to give special consideration to a particular species.
3. Consideration of special and unique habitats or habitat components.

Information obtained using these guidelines is then used in the planning process to affect the management of other resources.

This approach allows wildlife managers to make specific statements regarding which species, or groups of species, will be affected by management prescriptions applied to the habitat. Based on this, recommendations can be made through the land management planning process to minimize adverse impacts on wildlife habitats through management activities.

Another approach is to base the suitability index on objectively derived measures. Methods described by Brabander and Barclay (1977) and Asherin et al. (1979) both rely on habitat diversity to arrive at habitat quality ratings.

Brabander and Barclay (1977) utilized LANDSAT digital imagery data to establish wildlife habitat quality ratings for north central Oklahoma. The results of cover type classification of LANDSAT data is used to compute a vegetative cover diversity index. All plots are stratified based on these vegetative cover diversity indexes. Faunal and plant species data are then collected and used to calculate faunal species diversity and plant species diversity indexes. The three diversity measures are then subjected to correlation analysis to test the validity of using LANDSAT generated cover diversity measures as an indication of wildlife diversity. Signifi-

cant results were obtained (Brabander and Barclay 1977) lending credence to this method of evaluating habitat for wildlife as a whole.

Asherin et al. (1979) developed a similar remote sensing methodology based on the assumption that habitat quality is a direct function of habitat diversity for most terrestrial vertebrates. This method uses a stepwise multiple regression model to calculate habitat quality from habitat diversity measures computed from color infra-red aerial photographs. The most efficient predictor of habitat quality was a model containing bird species diversity as the dependent variable and with habitat strata diversity and habitat cover type diversity as independent variables. Although the prototype was developed in southeastern Montana, the procedure should have generic application, provided data are available to establish the regression models.

Federal agencies have put considerable effort into developing habitat evaluation procedures to meet their specific needs. Most of the following involve specific combinations and refinements of the approaches discussed previously.

In 1980, the U.S. Army Corps of Engineers reported on the development of a Habitat Evaluation System (HES) for planning purposes. The Habitat Evaluation System is based on a series of graphical relationships between key variables (e.g., percent overstory, number of snags, percent understory) for major habitat types and suitability indexes for those key variables representing their suitability for wildlife. The relationships are determined from literature sources and expert opinion. The Habitat Evaluation System describes habitat quality for a broad range of species rather than for individuals or groups of species. The output is a composite habitat suitability index ranging from 0 to 1 for each major habitat type. The relationships used in the Habitat Evaluation System are based on conditions in the Lower Mississippi Valley where the system was developed. Consequently, application in other areas requires modifications.

The U.S. Fish and Wildlife Service developed Habitat Evaluation Procedures (HEP) (U.S. Department of the Interior, Fish and Wildlife Service 1980, 1981; Schamberger et al. 1982) for use in evaluation of project impacts. The method is based on a species-habitat relationship that assumes optimal habitat for a species can be defined and that comparisons can be made between actual on-site conditions and the optimum. The Habitat Evaluation Procedures establishes a habitat suitability index value for a given species and combines the index value with an area measurement to give a habitat suitability per unit of area index as a final output. The method assumes that this unit value is directly related to carrying capacity. Like HES, the species-habitat relationship used in Habitat Evaluation Procedures are location specific. Such location specific applications are also found in Flood et al. (1977) and Baskett et al. (1980).

The Fish and Wildlife Habitat Relationships Program of the USDA Forest Service was developed for use in land management planning on National Forests (Nelson and Salwasser 1982). The method is based on labeling habitats according to dominant biological and/or phys-

ical attributes of sites and the specific environmental variables that are habitat resources for certain species. Three levels of detail for the biological and physical attributes of a site are evaluated in terms of diversity and selected species habitat capability for application in project and land use plans. Level 1 models develop habitat capability ratings for high, moderate and low densities of species. Known population densities are required to calibrate the habitat capability ratings. Level 2 models are frequently those developed by others (e.g., U.S. Department of the Interior, Fish and Wildlife Service 1980, 1981; Schamberger et al. 1982; and Williams et al. 1977). These models are assumed to integrate habitat variables and rate these variables in terms of providing habitat requirements. Level 3 models serve the purpose of aggregating all habitats within one area such as a National Forest. The approach developed by Thomas (USDA 1979) is one of several used for Level 3 models.

The Soil Conservation Service (SCS) evaluated changes in habitat quality as part of their 1980 Soil and Water Resources Conservation Act Appraisal, Part II. This effort was national in scope. Using existing inventory data, SCS established quality ratings by land use. A habitat quality index based on a scale of 0 to 1 is calculated for primary land uses (e.g., cropland, rangeland and forest land). Vegetation characteristics from the inventory are selected as being important indicators of habitat quality and assigned values. The quality ratings are determined by adding the weighted values of all variables for a given land use and dividing by the total of all weighted values. The indexes show only relative differences in habitat quality. This system does not measure suitability of the habitat for any one species and is subjective. Evaluation of projected changes in land use practices that would affect the habitat are made, permitting quality ratings for future conditions.

A property that characterizes most of the procedures discussed is that they have been developed and applied on a local scale. However, systems developed by Whitaker et al. (1976), Brabander and Barclay (1977), Asherin et al. (1979), and Hawes and Hudson (1976) do have regional application. Similarly, the HEP system (U.S. Department of the Interior, Fish and Wildlife Service 1980, 1981; Schamberger et al. 1982) has potential for evaluating habitat at the local and regional scales.

Analytical procedures that use species-habitat relationships can predict future habitat quality by analyzing changes in habitat structure variables projected by other models. The techniques discussed to this point do not provide a satisfactory connection between the measured attributes of habitat suitability and carrying capacity. In most cases, this association remains to be developed and tested. HES (U.S. Army Corps of Engineers 1980), HEP (U.S. Department of the Interior, Fish and Wildlife Service 1980, 1981; Schamberger et al. 1982), Forest Service Species Habitat Relationships (Nelson and Salwasser 1982), and systems developed by Brabander and Barclay (1977), Asherin et al. (1979), and Whitaker et al. (1976) assume that species habitat relationships are constant in predictions of future habitat

quality or suitability. As a rule, habitat quality cannot be expressed for wildlife communities, because as habitat variables change, habitat quality is reduced for some species and improved for others.

Species Occurrence Estimation

Techniques used to estimate species occurrence relate a set of habitat variables that are relatively easy to inventory to a species occurrence variable that is more difficult or expensive to obtain. Based on known relationships between these variables, models are developed and tested. The models are then used to predict species occurrence, provided that habitat variables can be inventoried which are the same type as are in the model, and their values are in the range of those used in building and testing the model.

Hoar (1980) attempts to predict the distribution of several endangered mammals in Virginia by using a system based on the distribution of environmental factors associated with the historical ranges of the species. The environmental factors are identified by a literature review and are classified as requisite factors or enhancement factors. Geomorphologic, topographic, land use, and physiographic data are included as input variables into the species historical range prediction. Computer analysis is used to synthesize habitat data and to describe probable distribution over large areas. One important shortcoming, however, is the fact that no probabilities are assigned to the prediction. Although variation in the suitability of a particular habitat to a particular species is accounted for, there is no method for determining the model's validity in terms of predicting the probability of occurrence.

Williams et al. (1977) developed a technique that associated probabilities with an estimate of occurrence. They adapted pattern recognition techniques from diagnostic medicine and coupled them with Bayesian statistics to evaluate wildlife habitat; their system is called PATREC. Kling (1980) was the first to field test the PATREC approach, and determined that it can be used to predict species occurrence. Kling (1980) developed such an occurrence model for golden eagles in the northern great plains region (southeastern Montana and northeastern Wyoming). Included in the model are variables that address both abiotic (e.g., presence of cliffs, snags, remote location) and biotic (e.g., prey density, shrub density, distance to other active nests) factors. Specific input variables are designated through literature reviews, expert opinion, or empirical field research. However, when based on other than empirical research, this method suffers from subjectivity. Minimizing the subjective component of this technique would appear to strengthen its reliability in estimating species occurrence.

Within the last decade there has been considerable development in the application of multivariate statistical methods in analyzing wildlife habitat. Shugart (1981) summarizes some reasons for this development:

1. Multivariate procedures intrinsically fit ecological problems (and data) dealing with habitat selection.

2. Many of the multivariate methods seem to be robust in the face of mild deviations from the underlying assumptions.
3. There already exists a hypergeometric interpretation of relationships among animals (niche theory) that is essentially based on a multivariate sample space.

Although multivariate techniques usually have habitat suitability as the output, the actual methods of determining species-habitat relationships and model validation make these methods more appropriately classified as estimates of species occurrence. Model building procedures involve comparing habitat characteristics of areas occupied and unoccupied by a particular species. For a review of possible input variables see Anderson (1980). Model output is usually expressed in terms of suitable or unsuitable habitat which is readily translated into "areas that should support" or "areas that should not support" the species of interest. The models developed by Smith et al. (1981) using discriminant function analysis provide an example of applying multivariate methods in predicting and simulating over time the availability of suitable habitat (i.e., percent area that should be occupied) for a number of eastern Tennessee birds. Input variables in the models include measures of foliage, branch, and bole biomass of trees, and stem density. Other applications of multivariate methodologies were reviewed in a workshop on the use of these statistical techniques in wildlife habitat studies (Capen 1981).

Estimation of species occurrence is an important contribution to interpreting species habitat relationships beyond the calculation of habitat capability or suitability indexes. The recent use of statistical techniques in the PATREC and multivariate approaches has greatly improved the value and interpretation of species occurrence models. As is generally true, most of the models need to be validated and field tested. Statistical methods are valid when assumptions concerning data used in these methods are adhered to carefully.

Population Quantities and Structure Estimation

Terrestrial wildlife population quantities could be predicted, in part, by incorporating components of the techniques discussed previously with information on population demography. However, demographic data on wildlife species is extremely difficult to obtain. Primarily for that reason, very few techniques produce accurate and precise information. Many species of wildlife do not lend themselves to direct estimation of mortality, fecundity, or population structure, because their mobility, behavior, or other characteristics make inventory of these variables difficult. In many cases, the techniques discussed predict potential rather than actual population quantities and tend to be characterized by subjectivity. Professional judgment is required to make the conversion from habitat to population numbers.

Early efforts to use demographic variables in models of population growth are simplistic; however, they

define the theoretical foundation for the more current, complex simulations.

Another class of techniques uses both habitat and demographic variables in a simulation model. These techniques tend to require intensive inventory data and have not been rigorously tested. The scale of application in most cases is for local situations. However, several techniques appear to be applicable at the regional level, and several others may be able to be modified for use at the regional level.

The problems associated with indexes of habitat value for wildlife and fish species which are used in resource planning are that these relative indexes are meaningless unless the functional relationships and actual population quantities can be determined. Three broad approaches attempt to establish measures of wildlife quantities and population structure.

Lentz (1973) described a system that epitomized the early species-habitat relationship approach. The technique translates a habitat quality rating into potential populations of four game species in the Alabama River Basin. In this system, species-habitat relationships are defined by a review of the wildlife research literature, and various habitat variables are inventoried to establish a habitat rating. The variables inventoried are species specific and include: overstory, midstory, and understory condition; percentage of cover types; presence of breeding and feeding habitat; stand age; interspersed; and years since last burn. Once the habitat rating is determined, a field biologist assigns a potential carrying capacity to the habitat rating. Carrying capacity values for each habitat rating are multiplied by acres in each habitat condition to derive a potential population. The derivation of this population value is based on the assumption that the species already occurs in the area or that it can be introduced.

Willis (1975) developed a nearly identical technique for several game species found in Kentucky. His method is based on described species-habitat relationships and measurement of habitat variables to arrive at a qualitative rating of habitat condition. A potential carrying capacity estimate is assigned to each habitat condition by field biologists or by reviewing past research reports. The primary difference between this technique and Lentz's (1973) is that the habitat variables inventoried by Willis are more definitive and do not require the subjective judgment of the evaluator in rating habitat condition.

Efforts to reduce the subjectivity inherent in systems dependent upon the literature or human judgment have resulted in several techniques that either establish species-habitat relationships empirically or determine the qualitative function relating the suitability index to abundance. The PATREC system reviewed earlier is also applicable to estimations of wildlife population numbers. This technique establishes the species-habitat relationships by associating particular habitat characteristics with relative population classes (e.g., high or low population levels) using a frequency of occurrence analysis. These frequencies of occurrence are translated into probability statements that can be used to

analyze areas of unknown potential for supporting a particular species. The output of this intermediate step is a group of probabilities that quantify the ability of the area to support the defined relative population classes. These probabilities then can be used to estimate a potential carrying capacity by incorporating historical population inventory data, which are used to calculate an average population level for each relative population class. The carrying capacity for the entire area is computed by summing the products of the average inventory estimates and their respective probability statements. Lines and Perry (1978) attempt to establish the relationship between an index of habitat quality and wildlife abundance using correlation and regression analysis. The habitat quality index is determined with the following model:

$$HI = \frac{\sum_{n=1}^3 (A_n) (X_{1,n}) (X_{2,n}) (X_{3,n})}{A_T}$$

- where: HI = wildlife habitat quality index
 n = subscript of the vegetation type (woodland, grain and seed crops, grasses and legumes)
 A_n = total acres in vegetation type n
 A_T = total acres in the plot
 $X_{1,n}$ = interspersed index for vegetation type n
 $X_{2,n}$ = factor accounting for the management characterizing each vegetation type n
 $X_{3,n}$ = estimated value of the distribution of wildlife drinking water

Correlations between habitat indexes and individual avian species populations were insignificant. However, a pooling of population estimates across all species resulted in significant positive correlations. Regression analysis provided the prediction equations for both avian diversity (number of species) and avian density from a measure of habitat quality.

Willis (1975), Lentz (1973), and Lines and Perry (1978) developed systems that calculate a habitat quality rating as an intermediate output with the final output, population quantity, based on this habitat rating. Giles and Snyder (1970) outlined an earlier system that did not consider this intermediate step but calculated potential populations directly from various habitat variables. Giles and Snyder assumed that the major factor in determining potential big game population density is the amount of available forage in an area used by animals during the critical or stressful periods of the year. Based on this assumption, habitat factors, such as year of origin (in a successional sequence), successional stage, elevation, acreage, percent acreage in winter range, quality factor (which accounts for nutritional variations), and percent composition, are inventoried. The system is capable of predicting potential populations at some future time, if no major habitat changes occur during the period of simulation.

A more recent application of the concepts outlined by Giles and Snyder (1970) is found in Wallmo et al. (1977), who developed a technique that evaluates current habitat quality for mule deer in north central Colorado. The method is based on an inventory of energy and protein supplied by available forage. A simple ratio between energy and protein required by the species and energy and protein provided by the habitat results in a prediction of potential carrying capacity. Existing data on the nutritional requirements of mule deer are sufficient to allow such an evaluation. However, nutritional and energy requirements are unknown for most species of wildlife.

Recent advances in multivariate analysis also have applications in predicting wildlife abundance based on habitat characteristics. Kitchings and Klopatek (1982) developed a regional level methodology using discriminant function analysis, for a few species representative of the western, central, and eastern United States. The models utilize acreages of Kuchler (1964) vegetation types and land-use categories as macro-scale input variables. The output is always in the same units as the input. In most cases, the units of input and output are a measure of abundance; however, in two cases, relative population levels (i.e., absent, low to moderate levels, high to very high) and animals killed on the road are used as surrogates. Although preliminary reports are positive, the models have not been validated.

A second group of techniques that estimate population quantities involves those methods that focus primarily on demographic input variables. Some of the earlier methods had several deficiencies. The most significant shortcoming was that many of the techniques offered only theoretical insight into the ecological processes involved in population dynamics. For example, the methods proposed by Gause (1934), Lotka (1924), and Volterra (1926) were developed to simulate predator-prey interactions and competition. However, their objective was not to predict animal population levels but to gain a basic understanding of the ecological processes involved in an environment where animal populations were competing for limited resources. The assumptions made to simplify the system, therefore, severely limited application to the real world. Another deficiency of Gause's, Lotka's, and Volterra's work was their failure to incorporate age structure into the model design. Despite the lack of realism and the simplicity of these systems, these early efforts provided the fundamental concepts and knowledge upon which many of the more modern and sophisticated models are based.

In response to the deficiencies of earlier methods, Leslie (1945) developed a matrix algebra model to account for the observed differences in birth and death rates associated with age. The population is differentiated into age groups, and the appropriate birth and death rates are assigned to each group. This modification increases the realism of population models to the point where later investigators have shown that abundance and population structure projections agree well with short-term experimental data for a number of wildlife species (Fowler and Smith 1972). Because it has

functioned effectively for a number of populations, this method has been incorporated into more recent models.

Pennycuick et al. (1968) made some additional modifications by incorporating both competition and time lag factors in the modeling effort. He modified Leslie's approach by making fecundity and survival density-dependent, and by introducing time lags. This model has shown some theoretical validity in predicting structure but has not been validated with empirical data.

Caswell (1972) and Comins and Blatt (1974) also identified certain weaknesses in the formulations of Volterra and Gause. Caswell proposed inclusion of factors to account for time lags, prey refuges, and "hunger" of the predator population. Comins and Blatt suggested a term to simulate the effects of environmental heterogeneity on population dynamics. Although the objectives of these models were not directed at predicting actual population levels, they identified factors that may be important in understanding the dynamics of population growth.

Methods to predict population structure in terms of age and sex for terrestrial wildlife, such as the Leslie (1945) method, are rare. The most common method of predicting population structure in wildlife management evolved from life table analyses. In this technique, population simulation focuses on the input variables of initial population structure and mortality rates specific to a species. Outputs from traditional life table analysis include mortality or survivorship schedules in a particular population. Widespread application has been limited because of the nature of the data requirements. Information on the initial age and sex structure must be estimated in order to predict population structure. However, as was stated earlier, such inventory data on wildlife species may be difficult to obtain and can be costly. The basic deficiencies in such an approach have been identified by Eberhardt (1969):

1. Life tables tend to ignore reproductive rates by considering only losses.
2. Life tables apply only to a population at a given point in time or to "stationary" populations, where it is assumed that births exactly balance deaths and that all rates are constant over the history of the population.

If the actual dynamics of a population are to be understood adequately, modifications to the "classic" life table approach are needed. To help resource managers evaluate a population's response to a certain set of circumstances induced by management or inherent in the ecosystem, Caughley (1977) found that both mortality and fecundity schedules must be considered. This approach was used in modeling both the statewide bobcat population for Wyoming (Crowe 1975) and a resident flock of Canada geese (Cromer 1978). Again, both reproduction and mortality factors, according to age class, were considered. Crowe used regression techniques to adjust his age-specific survivorship. Cromer used the simulation model PROGRAM ONEPOP developed by Gross et al. (1973) to describe his population, which also made use of harvest rates as a more specific breakdown of mortality.

PROGRAM ONEPOP was designed primarily for use on big game herds; however, application appears to be more generic, based on Cromer's usage on Canada geese. Data requirements include information on reproductive and mortality rates, age and sex structure, harvest rate, differential age kill, hunting effort, wounding loss, minimum age to harvest, minimum age to bias sex kill, and functional equations relating (1) density to production and energy used, and (2) age to weight and antler growth. Output from simulation runs concern population size, number of animals harvested, quality of animals harvested, weight of animals harvested, and energy required to produce yield. Preliminary tests of validity show good alignment between predicted and observed population levels for short-term simulations. Consequently, simulations for greater than 10 years may require modification of the functional relationships inherent in the model (e.g., modification of the equation for density dependent reproduction rates).

One of the most extensive applications of the life table approach through computer simulation was conducted by Craighead et al. (1974) on the Yellowstone grizzly bear population. The model was developed from long-term data and is capable of projecting future population levels. Consideration of age and sex allowed for management recommendations and prediction of possible effects resulting from various harvest or habitat management actions. The biological variables discussed above are included in the model structure along with the external effects of hunting and other management actions. Future projections are based on the assumption that reproductive rates would remain unchanged.

From the previous discussion of predictive techniques describing population quantities, two major categories of procedures can be identified:

1. Those that base their population predictions (usually for potential populations) on habitat factors.
2. Those that base their population predictions on population structure and dynamics (usually from inventories of actual populations).

From an ecological view, it is necessary to combine the two kinds of techniques in order to get a more accurate estimate of either potential or actual population levels. A system utilizing both types of information would also be useful in estimating the rates of increase or decrease of a particular population related to management prescriptions implemented within an ecosystem.

Davis (1967) was one of the earliest researchers to include both habitat and demographic variables in a single analysis for white-tailed deer. Dynamic linear programming was used to simulate deer populations over time. Input variables included: mortality, fertility, browse production, browse consumption, breeding requirements, and a mathematical expression representing the management objectives. This model provides insight into long-term yield, harvest schedules, and various management practices to maintain the deer herd. The technique also can be modified to incorporate multiple resource considerations. The most limiting aspect of this approach is that it assumes that all ecological relationships can be represented with a linear equation.

Rykiel and Kuenzel (1971) introduced nonlinear equations into a simulation model, in their study of the Isle Royal wolf community. By incorporating plant production, energy supplied by plants, respiration rates of plants as habitat variables; wolf population numbers, prey (moose) population numbers, and mortality rates as demographic considerations, Rykiel and Kuenzel found increased realism with nonlinear equations. The output from the model is expressed in forms of steady-state standing crop quantities for both predator and prey species. Powell (1979) applied these concepts in an investigation of the fisher/porcupine/snowshoe hare community in the Upper Peninsula of Michigan.

Multivariate statistical methodologies are also proving to be useful in efforts to model animal communities. Poole (1971) utilized factor analysis to model the populations of 10 species of insects. This technique specifies the predictive equations and identifies the underlying factors causing variance in population levels. Consequently, only those variables shown to have a significant effect on the output are included in the models. Variables in the analysis included interaction coefficients between each species along with gross environmental factors (i.e., minimum temperature, maximum temperature, and rainfall). Simulations over time agreed well with actual values for common species. One drawback of this approach is that it requires tremendous amounts of field work to inventory the population. This problem is characteristic of most simulation models and represents one of the tradeoffs when increased realism is desired.

Garcia et al. (1976) attempted to incorporate both habitat variables and population structure and dynamics variables into one model for a black-tailed deer population of western Washington. The demographic variables are essentially those used in Leslie's matrices. Basically, the methodology involves a "projection matrix" that represents the fecundity and survival rates for each age class. A population vector defining the initial structure is multiplied by the "projection matrix" to produce the new population structure, one time unit in the future. Demographic components are integrated with the habitat elements by simulating the relationships between habitat variables and density dependent population variables, such as fecundity and mortality. Distribution of seral stages, percent canopy closure, snowfall, and succession are some of the habitat factors used. Although the methodology and concepts applied in the modeling effort may be applicable to different and larger geographical areas, the model has yet to be validated, even on the area for which it was developed.

The model developed by Medin and Anderson (1979) represents one of the most intensive efforts at incorporating habitat, population structure, and dynamics variables in a model to simulate a population of mule deer in Colorado. They also considered environmental factors in order to link the population to its habitat. Habitat factors, such as percent ground cover, percent vegetational composition, food yield, food utilization, weather, soil moisture, and snow depth, were inventoried. Population input variables included age structure, sex structure, mortality, birth rates, and harvest

rates. The resulting model allows prediction of future population densities and structure, and examination of the effects of various harvest strategies. The concept of feedback loops was paramount in the establishment of this system. Feedback loops have been used extensively in describing physiological systems, and are now receiving more consideration in wildlife studies. Medin and Anderson's (1979) system can quantify changes in variables over time and allow more accurate projections into the future. The authors also discuss species interactions in terms of competition and predator-prey relationships but make no further mention of these factors when describing the input variables in the model. This model requires much data and demands very specific knowledge of the population biology of a species as well as the species-habitat relationships. Where sufficient data exist, such a technique could be very useful. Unfortunately, the necessary data for such models is generally lacking.

The quantities and structures of terrestrial wildlife populations can be estimated from either or both habitat and demographic variables. The analytical capability has been developed for quite sophisticated analyses, although the ecological theory supporting these approaches has not been generally agreed upon. Data, particularly for demographic variables, is deficient in terms of both availability and quality. These analytical approaches, however, are a valuable means of defining the most critical data needs.

Most of the recent population simulation models discussed, whether concerned with potential or actual population levels, have some provisions for predicting future population responses. However, certain assumptions are made that attach qualifications to the estimate. For example, the PATREC system (Williams et al. 1977) calculated the long-term potential mean population density that a particular set of conditions would support. The word "potential" is used because current models have been developed only for analysis of relatively stable environmental conditions. Features that may vary widely from year to year are not taken into account. Presence of the species in an area is assumed in these procedures. The fact that such assumptions are rarely valid is an admitted deficiency.

Several investigators have taken variables that are frequently assumed to remain constant and varied them to simulate population responses over time. In most cases, the hypothetically manipulated variables are those affected by management practices. Both Crowe (1975) and Powell (1979), for example, varied mortality rates resulting from increases in harvest rates to predict probable responses in the population. In addition, Medin and Anderson (1979) simulated the more long-term effects of varying harvest strategies in terms of sex, age, and time. Crowe, Powell, and Medin and Anderson, however, varied the habitat condition in terms of forage production. Similarly, Rykiel and Kuenzel (1971) introduced perturbations into the plant component of their Isle Royale community model and measured the subsequent response in the moose and wolf component over a 12-year period.

These techniques are directed toward small scale situations. Research dealing with regional or national level population estimates and population responses is essentially nonexistent.

Three levels of analytical techniques for evaluating terrestrial wildlife in land management planning activities have been reviewed. Habitat capability or suitability indexes are the most easily implemented methods available. However, they offer no direct information about the species occurrence or demographic attributes that respond to land management actions. Species occurrence and demographic models that incorporate habitat variables in their estimation procedures potentially solve that problem in the habitat models. The species occurrence and demographic data limitations, along with the lack of an agreed upon body of ecological theory, limit the utility of simulation models. Multivariate statistical techniques currently provide the most valid and rigorous means to evaluate land management actions on terrestrial wildlife.

AQUATIC WILDLIFE AND FISH ANALYSIS TECHNIQUES

Ecological analysis of aquatic wildlife and fish resources is most highly developed in determining habitat quality and population quantities in lakes and ponds. Recent efforts have been made to improve analysis models for rivers and streams. No techniques are available to predict species occurrence in any aquatic habitat, and few predict population attributes such as sex ratios and numbers, age structure and numbers, or size structure and numbers. Only rarely do analysis techniques predict aquatic wildlife resources over time. Most of the techniques are empirical. Cause and effect relationships and the interactions of the various ecosystem components have not been modeled for many situations. Simulation of ecosystem behavior by modeling would allow greater predictive accuracy and precision. Most of the techniques are applicable only to the present resource conditions, on a local scale, for one species or population.

Habitat Estimation

Efforts to develop predictive capability for aquatic habitat have been restricted to determinations of habitat quality or suitability for a given species. These techniques input only abiotic factors; they do not include biotic factors, such as the presence of predators, competitors, or disease, and they do not incorporate habitat size. Accessibility of the habitat to known reservoirs of the species in question seems to be assumed in these techniques. The methods depend on assembly of the habitat factors believed to be important in determining habitat quality for a species or group of species. Some of the procedures incorporate mathematical expressions for the relative importance of the factors, but none incorporates a description of the functional behavior of species-habitat nor species group-habitat systems. Also, they do not predict changes in habitat over time but only make predictions for the current situation.

The U.S. Fish and Wildlife Service has developed habitat evaluation procedures for individual aquatic and terrestrial species (U.S. Department of the Interior, Fish and Wildlife Service 1980, 1981; Shamberger et al. 1982). Habitat quality of a site, for a particular species, is expressed as a habitat suitability index (HSI). Species habitat requirements are obtained from the literature. A species response to each habitat requirement or abiotic variable (such as temperature) is graphed as a suitability index (SI) ranging from 0 to 1 (fig. 2).

Each variable is represented in an equation in such a way as to reflect its importance, relative to the other variables. Given an actual or a proposed situation, SI values are read off the various variable-SI graphs and those values are put into the HSI equation. Solution of the equation provides the HSI for a particular species.

The U.S. Fish and Wildlife Service has also developed an incremental method for assessing the effects of streamflow regimes on riverine habitats (Bovee 1978, Grenny and Kraszewski 1981). Depth, velocity, substrate, and cover information for a particular stream or river reach are used to establish a "weighted area" available as habitat for the various life stages of an aquatic species.

A guiding procedure being developed primarily by Henry L. Short^a identifies what he refers to as breeding and feeding niches in a series of vertical strata within a vegetation type. Where aquatic systems exist, strata within the water column are included. A two-dimensional matrix is constructed: strata with feeding niches within strata are plotted on one axis, and strata with breeding niches within strata are plotted on the other. Field observations of a species are used to define where, in the vertical strata, the species occurs when it is feeding and breeding. When several species are grouped on the matrix, they are said to be a guild. Common habitat requirements for the guild can be identified from the matrix. Cluster analysis is used to mathematically assist in grouping species into guilds. This procedure identifies habitat used by a guild of animal species and also may be used as the basis for evaluating habitat quality for a guild.

^aShort, Henry L., and Kenneth P. Burnham. A technology for structuring, evaluating and predicting impacts on wildlife communities. U.S. Fish and Wildlife Service, Western Energy and Land Use Team, Fort Collins, Colo. (unpublished manuscript).

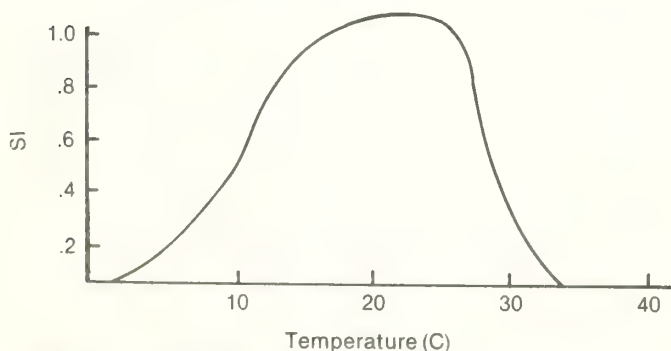


Figure 2.—Species response to the abiotic variable temperature, graphed as a suitability index (SI).

Swanston et al. (1977) developed an approach to predict habitat quality of streams for pink and chum salmon in southeastern Alaska. They tested 21 geomorphic variables that can be obtained from aerial photographs or topographic maps and reduced that number to 8 key geomorphic variables. A discriminant model is used, with the eight variables as input, to give a value that enables a particular stream to be categorized as either a "good" or "poor" salmon producing habitat. Intermediate quality streams can not be categorized. This technique is straightforward and relatively objective in both data collection and analysis. Theoretically, it can be applied anywhere for spawning habitat, although individual variables might need to be modified, added to, or deleted.

McConnell et al. (1982) developed an analytic procedure for predicting the habitat quality and fish species occurrence in planned reservoirs. This "pattern recognition" procedure involves developing a five-digit number, where each digit represents an aggregate of habitat attributes. The aggregate attributes are temperature, mineral turbidity, structure (cover, rocks, etc.), severity of water level fluctuation, and occurrence of shallow, protected coves (a function of mean depth and shoreline development). The digits, representing one of these aggregate attributes, range from 1 to 3. Rules were established for evaluating the five-digit number for a particular planned reservoir. Some subjectivity may exist in the use of these rules. The output of the procedure is a list of fish species that would be expected to exist in the reservoir, at some unspecified time, during the life of the reservoir, assuming those species had access to or were planted into the reservoir.

None of the habitat prediction procedures discussed previously can serve as an intermediate step to predicting population quantities. There is a need to develop procedures that quantify the relationship between the habitat quality and population quantities.

Population Quantities Estimation

Total Population Quantities

Prediction of population quantities has not developed much beyond identifying input variables. The only generic procedures available are simple or multiple regression analyses. Few attempts have been made to develop analytic techniques to predict population quantities over any time interval. Efforts to develop analytic procedures to predict present population quantities have usually included a search for and testing of variables. The selection of variables to be tested has usually been based on previous research and assumes that the variables have a biological and/or ecological relationship to aquatic wildlife and fish quantities. The relationship between variables and population quantities has been developed most often with correlation and regression analyses. Factor analysis has also been used with regression analyses (Harshbarger and Bhat-tacharyya 1980).

The geographic scope of the techniques varies, with most of them applicable to the local level. Most techniques deal with lakes and ponds, where it is easier to identify key variables and to determine interactions of components within the system, because lakes and ponds are relatively closed systems with sharper boundaries than rivers and streams.

A wide range of species are included, with emphasis on commercial and game fish. Research on invertebrates generally has centered on insects in streams or zooplankton in lakes, ponds, and reservoirs.

Binns and Eiserman (1979) and Burton and Wesche (1974) developed procedures for streams where trout populations are assumed to exist. Inputs to the analyses are primarily abiotic habitat factors.

Binns and Eiserman, working with 36 Wyoming streams, originally developed a technique that requires the use of 10 factors: late summer stream flow, annual stream flow variation, maximum summer stream temperature, nitrate nitrogen, fish food abundance, fish food diversity, cover, eroding stream banks, water velocity, and stream width. Because of the difficulty of processing macroinvertebrate samples to determine fish food abundance and diversity, those factors were replaced with vegetation abundance on the stream substrate. Fish food abundance and diversity is considered a function of this substrate factor. Field measurement values for the various factors are converted to rating values that are then used in multiple regression analyses to develop predictive equations for trout standing crop.

Burton and Wesche (1974), working on nine Wyoming streams and rivers, developed a technique that uses multiple and simple linear regression analyses to identify watershed and streamflow factors significantly related to estimates of trout standing crop. Four of these factors (watershed drainage basin area, mean drainage basin elevation, drainage basin forested area, and total drainage basin stream length) are used to develop a potential productivity index equation.

Most techniques for estimating fish population quantities for lakes, reservoirs, and ponds estimate fish production or fish standing crop. Fish yield or harvest, expressed in kilograms per hectare per year or pounds per acre per year, obtained from sport or commercial fisheries catch, is used as an index of fish production. Various inventory techniques used to estimate fish standing crop (expressed in kilograms per hectare or pounds per acre) include draining the body of water, killing the fish with poison, using mark and recapture methods, or netting intensively. Variables used to estimate fish production or standing crop include lake area, age, maximum depth, mean depth, shoreline development, outlet depth, water level fluctuation, storage ratio (ratio of water body volume to average annual discharge), carbonate concentration, total dissolved solids, and growing season. Simple linear or multiple regression are used to relate these variables to fish production or fish standing crop.

Rounsefell (1946) used regression analysis to correlate lake surface area to sport fish yield, commercial

fish yield, and total population. He found that as lake size increase, both fish yield and total population per acre decline. The lakes he studied range widely in size and geographic location in North America.

Carlander (1955) reevaluated the data used by Rounsefell (1946) and grouped the lakes by geographic area. He showed a negative correlation between standing crop and maximum depth in cold and warm water lakes. He also found a positive rather than negative correlation between lake area and fish standing crop for four of the five lake groups. Carlander suggested that Rounsefell's findings may be an indication of fishing effort per acre rather than fish production. Ryder et al. (1974) points out that it is generally accepted that small lakes are exploited more efficiently per unit surface area than are large lakes, when both are subjected to proportionally similar fishing efforts.

The relationship between lake water total mineral content and fish production was considered by Carlander (1955) and Rawson (1951). Carlander also related maximum lake depth with fish standing crop and showed a negative correlation between standing crop and maximum depth for trout. Carlander, using Rounsefell's (1946) data showed a positive correlation between carbonate concentration and fish standing stock in cold and warm-water lakes, and reservoirs. Rawson proposed that total mineral content provides a simple and useful indicator of edaphic conditions related to lake productivity. He cautioned that differences in productivity can not be ascribed to mineral content alone. Rawson (1951) suggested that lake morphometry is a more important factor. Rawson (1952) later investigated the relationship between mean depth and fish production (based on 25-year average catch) in 13 large North American lakes (surface area ranged between 460 and 31,820 square miles) and showed that the correlation was negative, thus emphasizing the importance of shallow water to lake productivity.

Hayes and Anthony (1964) showed a high correlation, using multiple regression, between fish productivity and a combination of lake area, lake mean depth, and methyl orange alkalinity. Ryder (1965) proposed a morphoedaphic index (MEI) for predicting the potential fish production of north-temperate lakes in North America. He used published data on 34 lakes and simple linear regression to establish this relationship. His morphoedaphic index is as follows:

$$MEI = \frac{\text{total dissolved solids (p/m)}}{\text{mean depth (feet)}}$$

Ryder et al. (1974) reviewed the literature relating to the development and subsequent use of the morphoedaphic index as an indicator of fish yield. He discussed the work of Jenkins (1968), who used multiple regression techniques to relate biomass yield for 210 temperate and south-temperate reservoirs in the United States to several abiotic factors. The four major multiple regressions completed by Jenkins were (1) standing crop on the morphoedaphic index; (2) standing crop on total dissolved solids; (3) sport fish harvest on total dissolved

solids, growing season, age, area, and shore-line development; and (4) commercial harvest on growing season, mean depth, storage ratio, age, and water level fluctuation. Jenkins concluded that the most meaningful regression was that of standing crop on the morphoedaphic index. Ryder et al. (1974) suggested that the lower efficiency of the MEI that was obtained with Jenkins' reservoir systems, compared with the results Ryder (1965) obtained for north-temperate lakes, was partly a result of the difference between reservoirs and lakes. They pointed out that reservoirs tend to be flowing water systems much more than do lakes. Many reservoirs have relatively low volumes and high flushing rates that result in a different type of primary production and energy flow system from that of lakes.

In a study of 20 Oklahoma reservoirs, more than 200 ha in area, Jenkins, (1976) using correlation and regression analysis, found storage ratio (the ratio of the reservoir volume at average pool to the annual discharge volume) to be the most important independent variable when regressed against fish standing crop. Other independent variables tested were: surface area, mean and maximum depth, outlet depth, shoreline development, growing season, water level fluctuation, total dissolved solids, and age of reservoir.

In another effort, Jenkins (1977) studied 166 reservoirs; all were more than 200 ha and all but six are south of the Mason-Dixon line and east of 100° W longitude. The reservoirs were divided into two major groups and into four subgroups. Hydropower and nonhydropower reservoirs were the major groups. The hydropower reservoirs are separated into mainstream (storage ratio less than 0.165) and storage reservoirs. The nonhydropower reservoirs were divided according to their water chemistry: those exhibiting dominant carbonate-bicarbonate ions and those exhibiting dominant sulfate-chloride ions. Jenkins used correlation and stepwise multiple regression analyses. The dependent variable was fish standing crop; the independent variables were reservoir area, age, mean and maximum depth, water level fluctuation, outlet depth, thermocline depth, growing season length, total dissolved solids, shore-line development, and storage ratio. Partial correlation analysis consistently showed total dissolved solids to be the most important independent variable.

Matuszek (1978) analyzed data from 22 large North American lakes and basins (surface area ranged from 187 to 82,414 km²) that had been moderately to intensively fished. He estimated the maximum sustained fish yield (MSY) for these lakes and used simple linear and stepwise multiple regression to test the relationship between MSY and abiotic and biotic independent variables. The independent variables he used were mean depth, total dissolved solids, morphoedaphic index, and bottom fauna standing crop. The highest coefficient of determination occurred for MSY and bottom fauna standing crop. A multiple regression of mean depth and total dissolved solids with MSY and a regression of MSY with the morphoedaphic index had slightly lower coefficients of determination.

Oglesby (1977) related fish yield to lake phytoplankton standing crop, primary production, and to the morpho-

edaphic index. The lakes he included were in North America, Great Britain, Europe, Africa, and Asia. He studied lakes ranging in size from 1 to 82,417 km². Using simple linear regression, he obtained the best fits for fish yield on summer phytoplankton standing crop for 19 lakes. A good correlation resulted from the regression of phytoplankton primary productivity on fish yield for 15 lakes. The regression of the morphoedaphic index on fish yield gave a lower coefficient of determination when 17 large lakes were included.

The relationship between primary production and fish yield has also been shown by other investigators. Hrbáček (1969) analyzed the data of Lyakhnovich et al. (1964) and found a good relationship between planktonic primary production and crop yield. McConnell et al. (1977) conducted experiments in small, artificial ponds. The ponds ranged in size from 0.001 to 0.1 ha, and were from 0.74 to 1.5 m deep. The ponds were inoculated with seston concentrates and macrophyte washings from several natural ponds. Fish species were tilapia hybrids, trout, goldfish, and a combination of tilapia hybrids and channel catfish. Fish yield was based on growth over the experimental period and expressed as grams per square meter per day. Simple linear correlation showed a good relationship, for all ponds taken together, for fish growth related to gross primary production in the ponds.

Aggus and Morais (1979) used multiple regression analyses to relate several independent variables to total fish standing crop and to standing crop of each of 14 different groups of fish (e.g., clupeids, carp, minnows, wall-eye, sportfishes). Those regressions were developed for 228 reservoirs in the United States, larger than 200 ha, in area at normal pool. The reservoirs were divided into those having (1) a thermocline; (2) dissolved solids composed of calcium-magnesium, carbonate-bicarbonate; (3) dissolved solids composed of calcium-magnesium, sulfate-chloride; (4) dissolved solids composed of sodium-potassium, carbonate-bicarbonate; or (5) dissolved solids composed of sodium-potassium, sulfate-chloride. The reservoirs were further classified as (1) hydropower storage; (2) hydropower mainstream; (3) nonhydropower; (4) reservoirs smaller than 70,000 acres, with total dissolved solids less than 600 p/m and growing season greater than 140 days; or (5) hydropower reservoirs in the Great Smoky, Ozark, and Ouachita Mountains. The independent variables for a reservoir were its age, area, mean depth, outlet depth, water level fluctuation, shore development, growing season, total dissolved solids, and storage ratio. The stepwise regression method of maximum r^2 improvement (Barret et al. 1976) was used to develop the best 1-, 2-, 3-, or 4-variable regression models.

Schueler and Sullivan (1967) quantified the potential commercial fish production in the midwestern United States. They estimated acres of commercial fishery habitat (lakes, reservoirs, and rivers) for the Upper and Lower Mississippi, Ohio, Missouri, Arkansas-White-Red, Red River of the North and Tennessee river basins. Fish standing crop classes were identified with an average standing crop value for each class. The estimated acreage for lakes and reservoirs in each river basin in the study, representing each standing crop

class, was tabulated. Total annual potential production of lakes and reservoirs, assuming potential production to be 25% of standing crop, was developed by standing crop classes. For rivers, an arbitrary standing crop value was assigned and the same 25% of standing crop was assumed to be the potential production. From known river commercial fishery acreages, total river production was estimated. The estimated potential production (lbs/acre) was compared with actual harvest figures.

Most techniques for predicting aquatic wildlife and fish population quantities as output emphasize identifying the key variables that can be used to predict the output. In almost all cases, the analytic procedures to predict aquatic wildlife and fish production are simple or multiple regression techniques. The techniques are primarily local in scale and do not have the capability to make predictions over time. One exception is Ricker (1971). He presented techniques for estimating fish production in fresh waters, including both lakes and rivers. Ricker's techniques deal with varying time and geographic scale and use various types of mathematical procedures, including calculus.

Another procedure which makes predictions over time is the model of fish biomass dynamics developed by Kitchell et al. (1974). This is an attempt to provide an ecologically meaningful model by including aspects of physiology, population biology, and trophic ecology. The model is based on principles derived from many studies of many species in addition to fishes. It was tested, using data on the bluegill (*Lepomis macrochirus*).

There have been several efforts to develop complex models to simulate varying portions of aquatic ecosystems. Prediction of population quantities over time can also be made with these models for the ecosystem components included. One example is the model of the pelagic zone ecosystem of Lake Wingra, Wisconsin (MacCormick et al. 1974). This model has seven compartments: phytoplankton, zooplankton, benthos, suspended organic detritus, permanent sediment, geologic sediment, and dissolved organic matter. The six model interactions are excretion and egestion by zooplankton, benthic insects, and fish; respiration and nonpredation deaths; reproduction; emergence of benthic insects; decomposition; and sedimentation. The input forcing functions are primary production by phytoplankton, and dissolved and detritus organic matter carried by wind and water currents from littoral zones to the pelagic zone and from storm sewers and runoff from terrestrial zones. Outputs from the model are losses of carbon and energy caused by respiration and losses of carbon and energy to deep geologic sediment. The loss of suspended and dissolved organic matter carried by water flowing out of the lake is assumed to be negligible.

The model of a cove of Lake Texoma, Texas-Oklahoma (Patten, Egloff, Richardson 1975) is extremely detailed and attempts to include every conceivable aspect of the cove ecology. Two of the objectives for this effort were to understand the interrelationships of the cove ecosystem as an ecological unit and to examine the basis in

these interrelations for responses to selected small, but realistic perturbations.

The phytoplankton-zooplankton-nutrient interaction model for Western Lake Erie (DiToro, O'Connor, Thoman 1975) was constructed to provide an aid in understanding and management of eutrophication. It contains compartments for zooplankton and phytoplankton allowing predictions of the biomass of these groups of organisms over time.

A final example of this type of complex aquatic ecosystem simulation model is the Lake Washington model (Chen and Orlob 1975) which includes compartments for, among others, algae, zooplankton, benthic animals, and fish. Biomass for those groups of organisms can be projected over relatively short periods of time (i.e., up to 1 year).

Harvest Population Quantities

An important fish management concern has to do with the relationship between the amount and kind of the harvest population and the response of ecosystems to that removal. As a result, numerous ecological analysis techniques have been developed for estimating the fraction of the total population that makes up a harvest population.

One harvest concept assumes that the production of an ecosystem can be partitioned into fractions. One fraction must remain in the ecosystem to maintain the structural and functional integrity and the productive capability of the ecosystem over time, while another fraction or maximum quantity is that which can be safely harvested. This is referred to as the maximum sustained yield (MSY) approach to fish harvest. Most analytic techniques to quantify the harvest of fish have been for single species of marine and large-lake fish populations.

Larkin (1977, 1978), Holt and Talbot (1978), and Caughley (1977) found major problems with the concept of MSY and the techniques for calculating MSY that relate to the larger problem of removal. MSY deals with the "dynamics of particular species or stocks without explicit regard to the interaction between those species or stocks and other components of the ecosystem" (Holt and Talbot 1978). For example, MSY does not deal with the facts that fish food webs, especially, are highly complex and each species both feeds upon and serves as food for several other species. MSY fails to account for the highly flexible fish growth rates which can change drastically as fish either gorge themselves or withstand starvation. Furthermore, life history events, such as maturity, are usually related to size rather than age. Maximum sustained yield is concerned only with the quantity and not the quality of the potential yield from the ecosystem. MSY also depends on a degree of stability and resilience of the resource that may not exist. Various changes in the system (e.g., change in species composition, proportion of predators to prey, size distribution of reproducing animals and resultant change in quality and quantity of eggs or young pro-

duced) or changes in external factors, such as climate, can significantly affect actual, compared to calculated, maximum sustained yield.

Thus, while an elaborate mathematical methodology has been developed for estimating maximum sustained yield for marine and large freshwater lake fisheries, a measure of the effects of this kind of harvest on all species of fish has not been developed for an entire ecosystem.

Despite its limitations MSY probably is useful as a first rough estimate of safe harvest amount for major commercial species. Many of the techniques for estimating MSY were developed to predict the effects of fishing on marine fish populations (Schaefer 1968, Schaefer and Beverton 1963, and Ricker 1958, 1975). Ricker (1971) presents the techniques for estimating harvest as well as fish production in fresh waters. Most of the techniques deal only with one species at a time and do not consider two or more interacting species. The fish system is generally considered to be in a state of dynamic equilibrium with average environmental conditions. The techniques also consider that the fish stock (biomass) of harvestable size is increased by the addition of recruits (results from reproduction) and by growth of the individuals in the stock; and fish stock is decreased by natural deaths and by the amount of fish taken by the fishery. It is assumed that for a fish population to maintain a state of dynamic equilibrium, there must be a homeostatic mechanism that, if mortality increases, either growth or recruitment will increase to compensate for the loss and bring the population back to the equilibrium level.

Two basic approaches have been taken in the various fisheries MSY models. One is called the "logistic model" approach associated with Schaefer (1954, 1957; the other is the "dynamic pool model" approach associated with Beverton and Holt (1957). Each of these approaches was originally developed for a specific fishery that imposed unique data limitations; each fishery, therefore, required unique assumptions.

Schaefer (1957), in developing the logistic model, was concerned with establishing the relationship between catch and fishing effort in the Pacific tuna fishery. Good statistics of catch and effort were available, going back to near the time when the fishery first started. Thus, the data covered the critical period when the population was close to its unfished equilibrium state. In his model, he combined the terms recruitment, growth, and natural mortality into one term: a "coefficient of population increase" as a single function of population size. Schaefer's model assumed that (1) the rate of natural increase responds immediately to changes in population density (i.e., time lags are ignored; this can be done where the rate of fishing effort change is slow, and/or when the life span of the fish is sufficiently short); (2) the rate of natural increase at a given weight of population is independent of any deviation in the age composition of the population from the steady-state age composition at that population weight; and (3) the fishing mortality rate is proportional to fishing effort. His model predicted catch from (1) the environmentally-limited (unfished) upper

value of the average population size; (2) the biomass of the fishable part of the population; and (3) the fishing effort. Provisions were included to deal with nonequilibrium conditions.

Beverton and Holt (1957) were concerned with techniques for assessing regulation on North Sea bottom-dwelling fisheries such as plaice and haddock. The investigators were concerned primarily with the effect of mesh size regulation but also had to consider the effect of changes in fishing effort. Some good catch and effort data were available, although important early data did not exist. Extensive age-composition data were available because age determination for these species is relatively easy. Thus, in the dynamic pool model, the assumptions are (1) equilibrium or steady-state conditions prevail, (2) a constant number of recruits enter the fishable stock each year, (3) the natural mortality coefficient is constant, (4) the length of a fish increases in proportion to its age and its weight varies as the cube of its length (growth), and (5) the relationship between fishing effort and fishing mortality is proportional. Beverton and Holt also assumed that the rates of recruitment, natural mortality, and growth are density independent. The model, using differential equations, computed equilibrium catch for various values of fishing mortality; it also predicted the effect on equilibrium catch as a result of a change in selectivity of the fishing gear and amount of fishing.

Anderson (1974) developed a simplified technique for estimating largemouth bass production and sustained harvest. This technique is based on a procedure originally developed by Allen (1950, 1951). It uses a graphic model that plots the number of fish as a function of average weight for the life span of a year class. The area under the curve (an approximate integration of growth and mortality rates) is an estimate of production during the life span of the year class. The area under the curve is also an estimate of annual production of the population if the population is in a steady state or if average growth rate and age distributions can be estimated. Potential harvest is defined as the total weight of fish of harvestable size that die each year. Potential harvest also can be estimated from the graph. Anderson assumed (1) the average age distribution, growth rate, and recruitment rate are in a steady state; (2) the annual production equals annual loss from mortality; and (3) growth and mortality are proportional (i.e., all mortality occurs during the growing season).

All of these approaches include only population quantity, structure and dynamics variables. Leslie matrixes (Leslie 1945; Usher 1972, 1976; Jensen 1971; Van Winkle et al. 1974, 1978) may provide a means for relating environmental effects to the population dynamics of fish.

Using rapid analog and digital computers, simulation models of fisheries have been developed to study the effects of effort control on abundance and yield of exploited fish populations. Most of these simulation models deal with commercial marine fisheries. Of the models discussed, only those of Walters (1969) and Orth (1979) apply strictly to fresh water species.

Silliman (1967) used analog computers to simulate the results of the New England cod fishery from 1932 through 1958. Paulik and Bevan (1963) modeled the sockeye salmon in the Puget Sound region between the time a group of mature fish entered the Sound from the open ocean until they arrived on the spawning grounds. Schaefer (1967) applied the Beverton-Holt dynamic pool model to develop a simulation model for estimating the effects of varying fishing regulations on the Peruvian anchoveta fishery.

Silliman (1966, 1969) developed simulation models for use with analog computers to derive data on population dynamics of whales. He also demonstrated the model for Pacific sardine, haddock, Atlantic cod, lake trout, skipjack tuna, bigeye tuna, blue whale, and fin whale. Forecasts of sustainable catch were made for the two species of tuna and the fin whale. Using Volterra equations to generate the biomass of one population as a function of the biomass of the other, he also modeled two competing populations. These models were applied to data of the competing pairs: Pacific sardine-northern anchovy, and the yellowfin tuna-skipjack tuna.

Walters (1969) used digital computers to develop a simulation model for fish population and maximum yield.

The model used age-specific natural mortality rates, growth rates, relative fecundities, and any desired stock-recruitment relationship. The model found solutions for density, growth, and yield by age group and joins age groups over time to predict yield. Orth (1979) developed a simulation model that predicts year-class strength, production, and yield of the freshwater largemouth bass. The model, which was age-structured and deterministic, has numbers, average weights, average lengths, biomass, yield in weight, yield in numbers, growth, and net production as state variables. Mortality from egg to age class I is estimated with a multiple regression equation that uses water level during spawning and water level fluctuation since the end of the previous growing season as independent variables.

Numerous sophisticated procedures have been developed to estimate maximum sustained yield. Almost all of these techniques are designed for single species stocks of animals (mostly marine fish). Some major assumptions are made because much of the needed information usually is not available. These assumptions can be sources of error in the predictions. No adequate techniques exist to define or predict the effect on an ecosystem of harvesting a part of that ecosystem.

MULTIRESOURCE INTEGRATION APPROACH

Techniques are needed to integrate planning for wildlife and fish resources with planning for other natural resources. Much work also is needed using integrated analysis research to determine if the output of the individual resource or functional analyses reviewed earlier can be incorporated into multiresource ecological analysis models.

A few existing techniques approach an integrated analysis of resources; however, they are still very much in the developmental stages. DYNAST (Boyce 1977) is an example of a technique that begins to address integrated ecological analysis of resources. Only the wildlife and fish components of this model were evaluated.

DYNAST considered timber, water, esthetics, and wildlife components. The wildlife submodel only addressed habitat quality and was highly subjective, relying heavily on expert opinion.

CONTINUING RESEARCH AND DEVELOPMENT NEEDS

More research is needed on the wildlife and fish resource aspects of the renewable resource, planning process. Research also is needed where economic and social analyses are fully integrated with ecological analyses. All spatial hierarchical levels should be included also.

Specifically, there is a critical need for procedures that objectively select, integrate, and further process the wildlife and fish resource analysis outputs for use as inputs to integrated planning models. Methods are needed to objectively select, from the many possible combinations of multiresource management practices, those practices or combinations that most benefit wildlife and fish, and other natural resources. Procedures are needed to objectively identify the ecosystem processes affected by the various management practices applied. The response of wildlife and fish resources to these management practices over various time and spatial scales also should be quantified. A procedure for determining the priority of species to be considered in ecological analyses also should be developed. This requires the development of criteria for establishing a priority for ecologically, economically, and socially important species. Improvement of the capability of techniques to estimate species population occurrence and quantities over various time and spatial scales also is important. Finally, techniques are needed, which apply to more species, and which estimate population structure and dynamics for various time and spatial scales.

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Hawkes, Clifford L., David E. Chalk, Thomas W. Hoekstra, and Curt H. Flather. 1983. Prediction of Wildlife and Fish Resources for National Assessments and Appraisals. USDA Forest Service General Technical Report RM-100, 21 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

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Keywords: Aquatic wildlife, terrestrial wildlife, fish, multiple resource assessments, wildlife prediction techniques, fish prediction techniques

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Rocky
Mountains



Southwest



Great
Plains

U.S. Department of Agriculture
Forest Service

Rocky Mountain Forest and Range Experiment Station

The Rocky Mountain Station is one of eight regional experiment stations, plus the Forest Products Laboratory and the Washington Office Staff, that make up the Forest Service research organization.

RESEARCH FOCUS

Research programs at the Rocky Mountain Station are coordinated with area universities and with other institutions. Many studies are conducted on a cooperative basis to accelerate solutions to problems involving range, water, wildlife and fish habitat, human and community development, timber, recreation, protection, and multiresource evaluation.

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Flagstaff, Arizona
Fort Collins, Colorado*
Laramie, Wyoming
Lincoln, Nebraska
Rapid City, South Dakota
Tempe, Arizona

*Station Headquarters: 240 W. Prospect St., Fort Collins, CO 80526



United States
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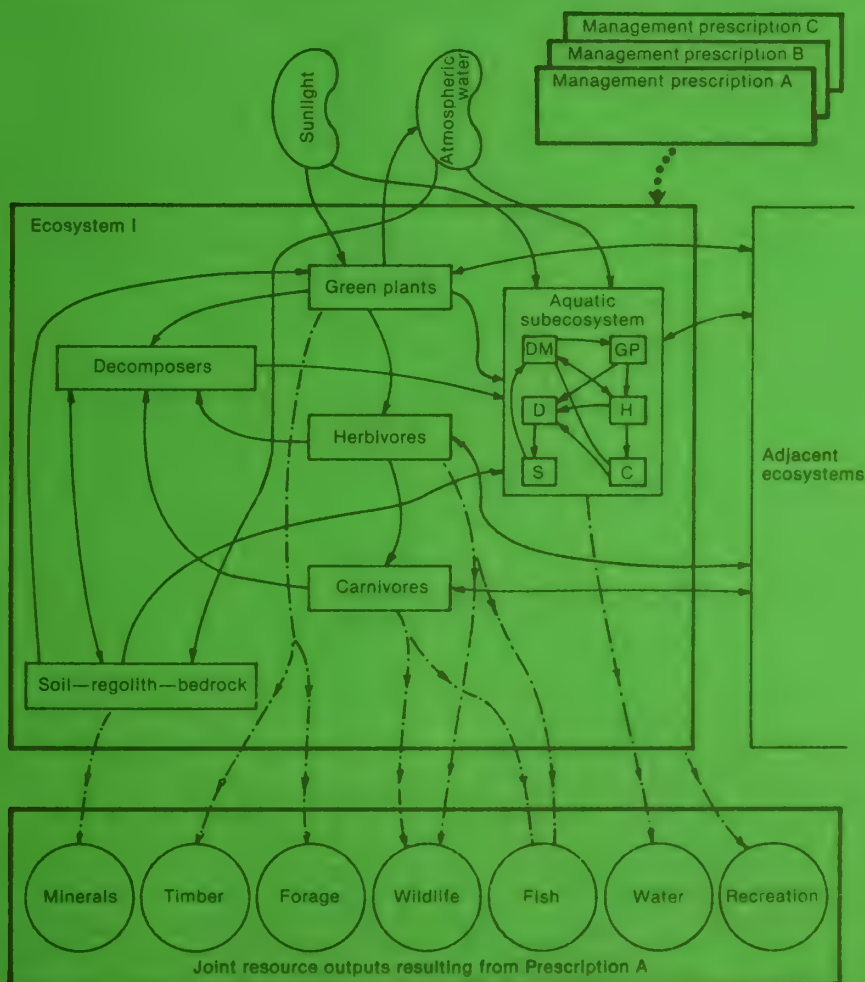
Fort Collins,
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General Technical
Report RM-101



Analysis of Multiresource Production for National Assessments and Appraisals

L. A. Joyce
B. McKinnon
J. G. Hof
T. W. Hoekstra



Abstract

This report gives an overview of the analytical methods used in integrated (multidisciplinary, multiresource, and multilevel) land management production analyses. The ecological and economic theory underlying both simulation and optimization methods are also reviewed.

Analysis of Multiresource Production for National Assessments and Appraisals

**L. A. Joyce, Range Scientist
B. McKinnon, Forest Economist
J. G. Hof, Research Forester
and**

**T. W. Hoekstra, Research Wildlife Biologist
Rocky Mountain Forest and Range Experiment Station¹**

¹*Headquarters is in Fort Collins, in cooperation with Colorado State University.*

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Analysis of Multiresource Production for National Assessments and Appraisals

L. A. Joyce, B. McKinnon, J. G. Hof, and T. W. Hoekstra

MANAGEMENT IMPLICATIONS

The dominant approach in integrated resource production analysis is optimization modeling, specifically multiresource linear programming modeling. Tradeoffs between alternative resource production strategies can be examined under a variety of decision criteria in these models. The theoretical basis for this approach is well-founded in the economic theory of production. The successful use of these models presumes the availability of benefit/cost information from supply/demand models, and the availability of production capability/response information from ecological models. Because this review focuses only on the production side of integrated resource analysis, it does not consider the availability of benefit/cost information.

There is no commonly accepted, ecological technique to analyze the simultaneous production of natural resources applicable in all ecosystems. Production capability/response information must be determined for the optimization models quantitatively for each resource, with the integration being qualitative. Advances in ecological research are increasing the degree to which the production capability/response relationship can be quantified. Resource analysts must select the appropriate analytical technique for their specific management problems.

The recent work of Wong (1980) in hierarchical modeling suggests promising ways to include multilevel considerations into integrated resource production analyses.

INTRODUCTION

National assessments of forests, range lands, agricultural lands, and associated waters of the United States are required by law. These assessments must be multidisciplinary, multiresource, and multilevel. This report is an overview of the analytical techniques used in integrated land management analyses, where integrated includes multidisciplinary, multiresource, and multilevel considerations.

Assessments, appraisals, and inventories are required by a number of laws. An assessment of renewable resources on forests and rangelands is required by the Forest and Rangeland Renewable Resources Planning Act of 1974 (RPA)² as amended by the National Forest Management Act of 1976 (NFMA)³. Appraisals of the soil, water, and related resources are required by the Soil and Water Resources Conservation Act of 1977 (RCA)⁴. Adequate inventories and documentation for development of policies and management of the nation's federal lands are required by the Federal Land Policy and Management Act of 1976 (FLPMA)⁵. The Multiple Use-Sustained Yield Act of 1960 (MU-SY)⁶ requires joint consideration of the major outputs from the national forests. Accounting for the environmental impact of management is required by the National Environmental Policy Act of 1969 (NEPA)⁷. The RPA, as amended by the NFMA, requires that these assessments be coordinated

with the requirements of the Renewable Resource Research Act, Cooperative Forestry Assistance Act, and the Public Rangelands Improvement Act.

Natural resource outputs, such as timber, wildlife, etc., can be analyzed in several different frameworks. Resource outputs can be examined functionally in terms of timber, range, wildlife, etc., or they can be examined in a multiresource context. They can be evaluated in ecological terms, economic terms, or sociological terms. Resource outputs can be analyzed at the level of the forest, the region, or the nation. Current production of resource outputs can be assessed, and projected trends of the current production can be made, or alternatives for future production possibilities can be projected.

Analytical techniques have been developed to integrate these different tasks specified by law and these different analytical frameworks. Optimization models are one method used to integrate multiresource, multidisciplinary, and future-oriented considerations. These optimization models require as input predictions about future conditions, which are developed from ecological and economic simulation models. Specifically, supply/demand models can provide benefit/cost (economic) information, and ecological analyses can provide production capability/response information. Social analysis models can predict the social impacts of the solutions given by optimization models.

Optimization models are the dominant integrated analytical technique, because they provide a framework for a quantitative analysis of resource production in an economic and biological environment. Other integrated approaches have not provided such a framework for integrating inputs from ecological, economic, and social analyses that is consistent with the currently accepted perspectives in ecology, economics, and social analysis.

²Public Law 93-378. *United States Statutes at Large. Volume 88, p. 476* (Pub. L. No. 93-378, 88 Stat. 476).

³Pub. L. No. 94-588, 90 Stat. 2949.

⁴Pub. L. No. 95-192, 91 Stat. 1407.

⁵Pub. L. No. 94-579, 90 Stat. 2743.

⁶74 Stat 215, as amended; 16 U.S.C. 528-531.

⁷Pub. L. No. 91-190, 83 Stat. 852.

This report focuses on the production or supply side of integrated resource analysis. The theory underlying the ecological and economic analyses is reviewed first. This presentation of ecological analyses reflects the state-of-the-art in its concentration on those theoretical approaches which have been applied in a limited number of cases. There is no commonly accepted ecological technique to analyze the simultaneous production of natural resources in an ecosystem. In contrast, there are standard analytical techniques to analyze the production of natural resources in an economic framework. These techniques have been expanded to analyze multi-resource production. These multiresource optimization modeling techniques are reviewed last, and include a review of those techniques which attempt to include multilevel considerations.

ECOLOGICAL ANALYSES OF PRODUCTION

Land management activities affect the structure and function of an ecosystem. Changes in the ecosystem cause changes in resource outputs (fig. 1). Analytical techniques predicting single resource production quantify those pathways in figure 1 pertaining to the single resource, such as timber or wildlife. A consideration of the impact of this single resource management on other pathways, and the joint production of resource outputs is necessary to evaluate the impact of management on the ecosystem. This is often done intuitively by managers in the field. The problem is quantifying the interaction of these pathways. Quantitative techniques

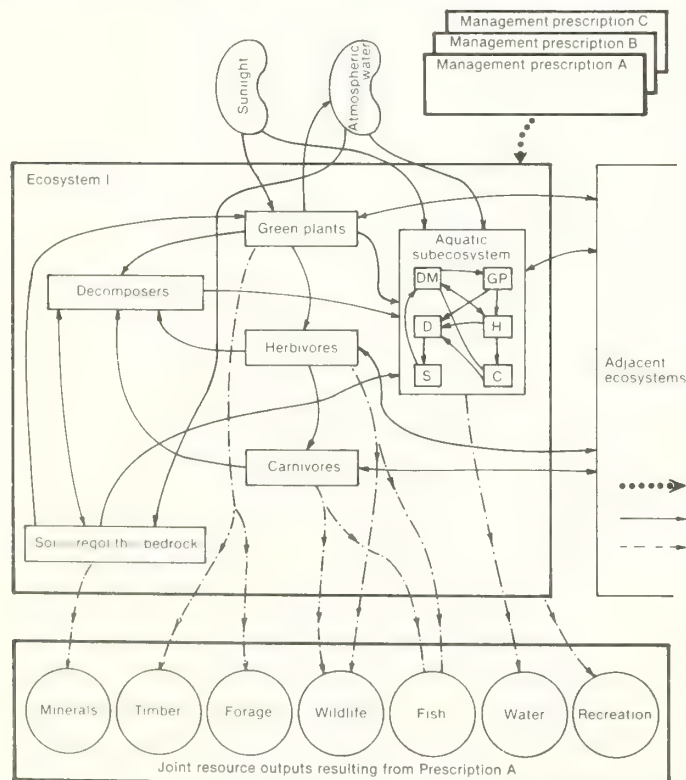


Figure 1.—Management prescriptions, ecosystem structure, and resource outputs.

predicting the production of natural resources have generally focused on single resource outputs (Alig et al. 1983, Hawkes et al. 1983, and Mitchell 1983).

Analysis of joint production using an ecosystem approach to natural resource management is relatively recent (Van Dyne 1969), and quantitative techniques are in early stages of development. Progress in this area has been hampered by insufficient and inadequate data, and by lack of ecological theory. Long-term records of ecosystem response to management under controlled conditions are rare. Although advances in ecological theory continue to be made, there is no single, unifying theory about ecosystem structure and function that could be applied to all ecosystems.

This review focuses on those theoretical ecological analyses which have been used to examine the impact of management. Different approaches in ecological research have increased understanding of ecosystem functioning, and this understanding has been used to examine the impact of management on the ecosystem's productive capacity. Ecosystem-level models, such as the large-scale simulation models of the International Biological Program, attempt to quantify all pertinent aspects of the ecosystem and track the impacts of management on the entire system. Another approach has been to quantify attributes of the ecosystem which could act as indicators of ecosystem health. When the complexities become too great to quantify, more intuitive approaches, such as an interdisciplinary team, have been used to estimate the impact of management. Because of the diversity of approaches, the resource analyst must select that technique which best describes the impact of the particular management activity being considered.

Ecosystem Theory

Ecologists have struggled to define a theoretical structure for ecological research (Haug 1981), and these continuing struggles approach the problem from two directions. The first approach views the ecosystem as a system and attempts to define a general theory of ecosystem behavior applicable to all types of ecosystems. The theoretical work of Miller (1978) is an appropriate example of this category. The second approach focuses on attributes of the ecosystem and attempts to define the relationships of the parts in order to describe the whole. Large-scale simulation models, such as the shortgrass prairie model, ELM (Innis 1978), are examples of this approach.

Ecosystem Approaches

Ecosystem-level theories represent frameworks integrating ecosystem structure and function. The approaches differ in their theoretical assumptions and their degree of quantification. Examples of these ecosystem-level theories include: the system dynamics approach of Gutierrez and Fey (1980), the living systems theory of Miller (1978), the linear modeling approaches

of Patten (1975, 1976), and the energy analysis of H. T. Odum (1971). Further development of these theories may suggest a unifying theoretical framework for the analysis of joint production in an ecosystem. Currently, some of these approaches (H. T. Odum 1971) are being applied to natural resource problems and have provided valuable information to planners (Littlejohn 1977). Because of the success of H. T. Odum's (1971) approach, it is briefly summarized.

H. T. Odum and co-workers at the University of Florida state that all systems obey three laws of energy. The first law of thermodynamics was restated by Odum and Odum (1976) as the law of conservation of energy in an ecosystem. "The energy entering a system must be accounted for as being stored there or as flowing out" (Odum and Odum 1976). The second law of thermodynamics was restated as the law of degradation of energy. "In all processes some of the energy loses its ability to do work and is degraded in quality" (Odum and Odum 1976). To these two laws Odum and Odum (1976) added a third law, first conceptualized by Lotka in 1925. Referred to as the Maximum Power Principle, this law states, "That system survives which gets most energy and uses energy most effectively in competition with other systems." It is this third law which suggests those ecosystems survive which maximize the input of energy and use it most efficiently to meet survival needs.

The impact of channelization of the Gordon River, near Naples, Fla., was assessed using Odum's approach (Littlejohn 1977). The relationship between the changing patterns of land use and regional water regimes was quantitatively expressed, and the role of wetlands in maintaining aquifer stability was evaluated in three alternative land-use scenarios, including full development. The model demonstrated the impact of development on aquifer stability and provided opportunities to test several water management plans. The Collier County Commissioner adopted, in principle, the final contract report^a as a development plan for the region.

Ecosystem Attributes

Many ecosystem processes have been described and mathematically modeled. Because ecology is a young science, the theoretical interpretation of each process or attribute may not be universally agreed upon, and, in fact, the significance of the attribute may be in question. Johnson (1977) presented a set of ecosystem attributes commonly recognized by ecologists. These attributes included: niche; habitat; carrying capacity; community characteristics such as diversity, trophic organization, and populations; competition; succession; resilience; growth; nutrient cycling and energy flow; and evolution.

Ecological studies have described parts of ecosystem structure and function in terms of these attributes (E. P. Odum 1971, Krebs 1972, and Ricklefs 1979). Further studies have examined the effect of ecosystem disturb-

ance on these attributes. This understanding can then be used to examine the impact of management on the individual attributes as an indicator of the impact of management on the entire ecosystem.

A thorough review of ecosystem attributes and their numerous and diverse models is not possible here. Instead, the types of models that have been used to describe these attributes in a resource management application are briefly described.

The ecosystem attributes of habitat space and carrying capacity have been used extensively to analyze the effects of management on wildlife and fish populations. Habitat space is defined as the distributional relationship of species to environment (Johnson 1977), and the selection of a habitat has been modeled as a function of environmental pattern, competition, or population densities (Rosenzweig 1981). Carrying capacity of a species refers to that population size which is asymptotically approached when growth of a population is represented mathematically by a logistic equation. The behavior of a population around its carrying capacity varies, depending upon the population control mechanisms of that species.

Population growth is a function of interacting abiotic and biotic limiting factors (Johnson 1977), and the types of models predicting population growth are as diverse as the populations themselves. The types of models include differential equation models (May 1973), matrix models (Usher 1972), and simulation models containing several different mathematical formulations. Factors incorporated in these models include variable birth and death rates, competition, predation, density of population, and spatial complexity of the environment. Hawkes et al. (1982) reviewed this literature on models of habitat space, carrying capacity, and populations in natural resource management.

A species niche can be described as the environmental dimensions in which that species alone can exist. This would include temperature ranges, humidity and salinity ranges, and biological factors such as prey species. Based on the premise that two species cannot co-exist in exactly the same niche, species interactions are examined by measuring niche dimensions, such as bill length and width of birds. Franz and Bazzaz (1977) used the theory of niche differentiation to determine the relative impact of alternative reservoir designs on vegetation in the backwater zone of the reservoir. The occurrence of each tree species was described in a probability distribution as a function of flood frequency at each of three points along the river. These distributions characterized the ability of each species to survive and grow, given the particular frequency of flood stages at that point along the river. Changes in flood stage frequencies, resulting from each reservoir design, were simulated with each of these species distributions to determine species changes along the gradient and, thus, community impact. Recommendations were made for the design that produced the least impact in community composition.

The matter of how to describe diversity, at either the species level or the ecosystem level, has received considerable debate (Ricklefs 1979). Measurements of plant

^aOdum, H. T., C. Littlejohn, and W. C. Huber. 1972. *An environmental evaluation of the Gordon River area of Naples, Florida, and the impact of development plans*. Department of Environmental Engineering Sciences, University of Florida, Gainesville.

and animal species diversity provide an overall estimate of the variety or number of species (species richness) and their relative abundances (evenness of distribution). There are many sampling problems associated with field measurements of diversity, and all of the diversity indexes appear to be sensitive to these problems (Ricklefs 1979).

Hurlbert (1971) discussed the many semantic, conceptual, and technical problems associated with the measurement and interpretation of species diversity. He concluded that communities with different species compositions are not intrinsically arranged in linear order on a diversity scale. Therefore, although a diversity index may show a correlation with other properties of a community or environment, that correlation is not evidence that the index is either appropriate or useful. Similarly, two or more sets of data could have the same relative abundances of totally different species and still have identical diversity index values.

Species diversity on an island has been shown to be a function of the total land area of the island and the distance from the mainland (MacArthur and Wilson 1967) and can be viewed as an equilibrium between immigration and migration. Islands can be interpreted as units of land surrounded by a barrier such as water, or human development. Island biogeography theory has been further refined by field and mathematical simulation experiments. Shaffer (1981) outlined the implications of this theory in the determination of the minimum viable population size of a species, and various authors in Soule and Wilcox (1980) addressed the implications of this theory in the management of wildlife and the design of wildlife reserves.

Mathematical models have been developed to describe trophic structure and the impact of change on that structure. May (1973) recognized four primary features of trophic structure: the number of species involved, the nature of their interconnections, the number of connections per species, and the intensity of interactions between web members. Paine (1980) stressed the importance of the intensity of interactions between web members. According to Paine, trophic links are unequal in strength. The relative strength of interaction is partially the result of the consumer's density and partially the result of the limitation on the predation process imposed by prey size. Strong interactions can be determined experimentally by examining the impact which removing a species has on a community. Human activity has indirectly tested this theory about the importance of interaction strength, and the effect of a species reintroduction was successfully predicted from this theory (Paine 1980). Most mathematical models of food webs do not incorporate interaction strength. The importance of this concept suggests that those models that examine interaction strength will become increasingly valuable (Paine 1980).

The patterns of plant populations in succession have been theorized for all ecosystems (E. P. Odum 1971) and quantified for several ecosystems. Simulation models of plant succession exist for a variety of ecosystem types: western coniferous forest (Reed and Clark 1979); nine

Montana habitat types including lodgepole pine, ponderosa pine, Douglas-fir, subalpine fir, whitebark pine, and spruce communities (Kessell and Potter 1980); Appalachian deciduous forest (Shugart and West 1977); north-eastern hardwoods (Botkin et al. 1972); aspen (Cattellino et al. 1979); and grassland (Gutierrez and Fey 1980, Bledsoe and Van Dyne 1972). None of these models include wildlife or fish population changes.

Energy flow and nutrient cycling have received much study at the ecosystem level in recent years. As both nutrients and energy flow through the ecosystem, each has been used as a currency to include all ecosystem component interactions in one model.

Richey (1977) studied the phosphorus cycle of a lake using a simulation model. The model building process involved interactions with field work, where parameters suggested in the model-building process were measured in the field. Once the model was constructed, certain questions were asked of it. For example, "Is it important to know the flux as well as the concentration of phosphorus in determining its importance in a lake?" (Richey 1977). The response of the model to such questions was used to suggest further experimental work. Several simulation models of energy flow and of nutrient cycling have been used in a similar manner in other types of ecosystems.

Energy flow and nutrient cycling have also been studied to understand the effects of management on ecosystem processes. For example, a model describing the sulfur cycle of a grassland system was used to examine the effects of increased sulfur dioxide from a nearby coal-powered electricity plant (Coughenour et al. 1980).

Resilience is the ability of an ecosystem to recover from an external perturbation. Ecosystem response to perturbation is usually nonlinear and is a function of the magnitude, frequency, and type of perturbation. Quantifying this attribute has been difficult because of the inadequate understanding of the ways ecosystems respond to stress. Cooper and Zedler (1980) recognized the importance of this concept in environmental impact and incorporated it into their process, although subjectively.

Johnson (1977) included the attribute evolution in his list, and what is, perhaps, most important for natural resource models is not the process of evolution itself, but the concept that systems evolve. While the effects of evolution may take a long time to actually see, the process is going on continually. This evolutionary viewpoint is evident in Holling's (1978) work on analytical techniques for environmental impact assessment which can readily incorporate change.

Environmental Indexes

Environmental indexes synthesize information on the impact of an activity on the environment. Two general categories of indexes can be seen: (1) those indexes which synthesize several environmental measurements such as an air pollution index, and (2) those indexes which synthesize the intuition and experience of field experts or managers, such as quality of life indexes.

Ott (1978) pointed out six basic uses of environmental indexes:

1. Resource allocation—to assist managers in allocating funds and determining priorities;
2. Ranking of locations—to assist in comparing environmental conditions at different locations;
3. Enforcement of standards—to determine whether standards are being met;
4. Trend analysis—to determine changes in environmental quality over time;
5. Public information—to inform the public about environmental conditions;
6. Scientific research—to reduce a large quantity of data to a form that gives insight to the researcher conducting a study of some environmental phenomena.

The use of environmental indexes is often contrasted with the use of a mathematical model in determining environmental impact. The construction of a mathematical model of an ecosystem may require more detailed data and theory than is currently available. Therefore, it appears more attractive to use an environmental index. Ott (1978) stressed that index development must begin with a carefully defined concept of the purpose of the index and that the original purpose must be respected when the index is used. Ott (1978) pointed out that because indexes are meant to simplify, in the process of forming an index, some information is lost. This is a problem only when the index is later used to answer a question it was not designed to address.

Cooper and Zedler (1980) proposed a regional environmental assessment process that involved mapping and subjective expert ratings of the impact of an activity. They felt that, no matter how small, every project should be viewed in a regional setting, so that the cumulative impacts likely to be missed in case-by-case appraisals would be identified. Relative levels of ecosystem sensitivity were assigned to each tract of land in the region by a team of scientists. Ecosystem sensitivity was characterized by three components: significance of the ecosystem regionally and globally, rarity or abundance of the ecosystem relative to others in the region or elsewhere, and resilience of the ecosystem. Determining ecosystem significance required evaluating its biological importance in terms of species composition, resource outputs, genetic reservoir, scientific value, and esthetic value. Ecosystem size and occurrence are the factors involved in evaluating rarity. The resilience of an ecosystem is a measure of a system's ability to absorb environmental stress without changing to a recognizably different ecological state. Each unit of land was rated at one of four sensitivity levels, from minimally sensitive to maximally sensitive. The sensitivity ratings were meant to provide information on the likely impact of an activity. Cooper and Zedler (1980) recognized that the use of an interdisciplinary team to evaluate ecosystem sensitivity was subjective; however, the degree of agreement attained among the team members suggested this was a worthwhile approach.

Another example of attempting to evaluate the importance of an ecosystem can be found in the Ecological

Index method (Klopatek et al. 1980). It is based on the following:

1. identifying important ecological resources within the area,
2. determining the extent of those resources, and
3. computing the area quality value by creating a matrix which combines the magnitude of a particular resource and the importance of that resource.

The overall index is calculated using nationally available data on vegetation, avian species, mammalian species, and threatened and endangered species. The Ecological Index represents a hierarchical rating system in which all parameters are analyzed, using three levels of stratification: national, regional, and ecoregion section. The index filters information from one level to another. Although this index incorporates both habitat and species data, it lacks an aquatic component. However, it appears that such a component could be included with only slight modification.

The Wildlife Habitat Quality Index (USDA 1981) was described in the RCA 1980 Appraisal, Part II. Indexes of habitat quality, which reflect the overall value of habitat for a wide variety of vertebrate species, were developed for croplands, pasturelands, range lands, forest lands, wetlands, and aquatic areas (rivers, streams, and ponds). Availability of food and cover for wildlife was considered to be a function of land use. Weighted values were developed for several resources (e.g., forest lands, croplands) based on factors that contributed to habitat quality (e.g., grazed versus ungrazed forest). Wildlife habitat quality was estimated using data from the 1977 National Resource Inventories (USDA Soil Conservation Service 1977).⁹ Water quality (e.g., nutrient levels, sediment loads) and minimum in-stream flow requirement data were considered to be essential for estimating quality of fish habitat. In addition to the water quality and water supply for farm ponds, the size and location of the ponds were considered important in limiting fish production. Estimates of fish habitat quality were made using data from the Second National Water Assessment (U.S. Water Resources Council 1978). Information on wildlife or fish species (e.g., presence or absence, relative abundance) was not included in this method.

Short¹⁰ developed a technique whereby wildlife communities can be evaluated on the basis of vegetation structure. The physical strata in a cover type where a species feeds and/or breeds are used to classify the species into cells within a species-habitat matrix. The wildlife guilds that may occur in a cover type are determined by cluster analysis. Impacts on wildlife are then determined by examining the changes in the physical strata of the vegetation cover type. While the approach looks at species guilds, an index of total impact could be computed.

⁹USDA Soil Conservation Service. 1977. *Erosion Inventory Instructions for County Base Data*. Internal memo dated March 25, 1977. 7 p. Washington, D.C. Also, USDA Soil Conservation Service. 1977. *Erosion inventory instructions for the PSU and point data collection*. 20 p. Internal memo dated June 1977. Washington, D.C.

¹⁰Short, Henry. 1981. *A technology for structuring, evaluating, and predicting impacts on wildlife communities*. (Unpublished manuscript).

Interdisciplinary Team Approach

The use of a team of experts to estimate environmental indexes or assess environmental impacts has received much attention because of the difficulty in obtaining data (Suffling 1980) and the difficulty in quantifying ecosystem-level relationships (Cooper and Zedler 1980). An intuitive approach, such as a team of experts, relies on the experts to integrate their experience and the current knowledge to estimate the impact of management on the ecosystem under a wide variety of situations. Intuitive approaches have been used to estimate environmental variables not easily quantified and to estimate environmental variables which there is insufficient time to measure.

Examples of the first situation include the estimation of ecosystem sensitivity proposed by Suffling (1980) and the regional environmental assessment process proposed by Cooper and Zedler (1980). Another example would be the qualitative estimates of the 12 resource outputs in the FRES study (Kaiser et al. 1972). Among the estimated resource outputs were air quality, soil stability, rare and endangered species, depressed area impact, soil quality, and flexibility for future management.

An example of the second intuitive approach would be the forest planning process in the National Forest System. There, a team of experts, referred to as the interdisciplinary team (ID team), must develop a management plan for a forest. The plan must ensure coordinated planning among outdoor recreation, range, timber, watershed, wildlife, fish, and wilderness opportunities.

Where quantitative estimates of the ecosystem's responses to management are necessary, the ID team is directed to be as quantitative as possible. Where quantification is not possible, the following guidelines from Forest Service Manual (FSM 1920) are given.

For any action taken within the planning process that must rely on assumptions (or statistical inference) in lieu of specific data or information, the responsible official and the interdisciplinary team shall:

1. Identify the specific analytical technique and associated assumptions used.
2. Document why particular assumptions were used.
3. State the basis upon which the analytical techniques and corresponding assumptions were selected and the advantages and disadvantages compared with the relevant state-of-the-art techniques.
4. Ensure and document, to the extent practicable, the consistency of assumptions with those used in other land and resource management planning efforts, including the national program.
5. Assess the consequences and implications of using the assumptions.

The team approach appealed to Cooper and Zedler (1980), especially when the team members had a strong consensus in their estimations. Cooper and Zedler (1980) said that mathematical models in resource management do not adequately synthesize the appropriate information for impact assessment. They indicated that current models estimate the effects of environmental change on the productivity of ecosystems, but are less successful in

predicting shifts in species composition of plant and animal communities, particularly terrestrial communities. Intuitive approaches integrate the person's experience and knowledge in a way that is not easy to track, but that may fill some gaps that are unavoidable in forest planning or research.

Simulation Modeling

Model Building

Simulation refers to mathematical and statistical models that have been implemented on a computer. Their use in ecology and resource management has greatly increased in the past 15 years. The process of constructing a simulation model can be broken into five stages: conceptual, diagrammatic, mathematical, computer programming, and validation/verification.

In the conceptual stage, the modeler's experience and intuition suggests important features about the system's structure to be modeled, given the questions being asked about the system. In the diagrammatic stage, word models and diagrams are used to structure the model. The most commonly used diagrammatic model is the "box-and-arrow" diagram, or the compartment diagram. There, boxes represent components or compartments of an ecosystem, and the arrows show inputs to and outputs from each compartment (fig. 1). Inputs to a compartment coming from outside the ecosystem are referred to as forcing functions, or driving variables, or exogenous variables. State variables refer to the contents of the boxes, and the parts of the system they represent. The choice of which parts of the system to model as state variables is made in the conceptual stage.

The complexity represented in the diagrammatic model is referred to as the degree of aggregation. Because a model never can completely replicate the system, compartments of the real system may be combined in the model. One example would be combining all plant species into one compartment instead of modeling each plant species.

In the mathematical stage, the structure and function of the ecosystem are described in equations. The relationship between state variables and/or flows is determined from experimental work, previous models, or the modeler's intuition. For example, the growth of a plant (state variable) could be represented as a function of sunlight, temperature, and precipitation, all driving variables, where the function was determined from field research.

The fourth stage in the modeling process is the computer programming stage where the mathematical equations are written into a computer program. The internal logic of the computer program is checked.

The last stage in the modeling process is the validation/verification stage. The model is tested under a variety of situations. An error analysis may be performed to determine the magnitude of error propagation in the model. A sensitivity analysis may be performed to determine how sensitive the model is to changes in the parameters of the equations. And, finally, the model output is com-

pared with different field data that were not used in constructing the model to determine how well the model mimics the real world.

The modeler's perceptions about the ecosystem affect the internal structure of the simulation model. Energy flow has been used to connect all ecosystem interactions in some models, while nutrient cycling has been used in others. Some models focused on population fluctuations, others concentrated on the dynamics of one animal and its environment. Environmental boundaries may be relatively small, as in the algal-fly community of a hot springs (Wiegert 1977), or large, as in the world resource production and consumption of the world (Meadows et al. 1972). The mathematical equations in the model may be based on years of research, as in the model of nutrient cycling in a *Liriodendron* forest (Shugart et al. 1976), or they may be based on empirical relationships where the theoretical underpinnings from research are lacking.

The various modeling approaches differ in terms of the type of mathematics used to describe the ecosystem. Differential equations and difference equations have been used in simulation models of energy flow, nutrient cycling, and population dynamics. Some algebraic models have been constructed also. Penning de Vries (1976) noted the increased acceptance of the state variable approach as a basic element of the simulation of continuous systems. Other modeling approaches have been reviewed by Van Dyne and Abramsky (1975), Holling (1978), and Shoemaker (1977).

Applications of Simulation Models

Van Dyne (1980) reviewed the development of simulation models, in the context of a review of systems ecology. The term "systems ecology" refers to the "ecology (which) deals with the structure and function of levels of organization beyond that of the individual and species" (Odum 1964). Van Dyne (1980) presented the following characteristics of systems ecology:

1. consideration of ecological phenomena at large, spatial, temporal or organization scales;
2. introduction of methodologies from other fields that are traditionally unallied with ecology;
3. an emphasis on mathematical models;
4. an orientation to computers, both digital and analog devices; and
5. a willingness to develop hypotheses about the nature of ecosystems.

The application of simulation models in ecology has been an integral part of the development of systems ecology. Some of the earliest applications of ecosystem simulations were those of Odum (1960) and Olson (1963) on an analog computer, and Garfinkel (1962) on a digital computer (Wiegert 1975). Since these attempts, simulation modeling has diversified greatly. Simulation models of ecosystems range from large, complex systems of equations to small sets of differential equations.

Models constructed for natural resource management differ in structure from modeling approaches in ecolog-

ical simulation. This difference was pointed out by Spofford (1975) for aquatic systems models and Reed and Clark (1979) for forest growth models. Spofford (1975) contrasted the water quality models, based on the Streeter-Phelps approach which predicts dissolved oxygen or algal concentrations, with aquatic ecosystem models which predict trophic levels and species populations. He noted that the biological mechanisms were more complex in the models of aquatic ecosystem than in the water quality models. The latter models were also based on relationships which were more empirical.

Applications of simulation modeling vary greatly; in most cases, the simulation model was built for a specific ecosystem, and often for a specific set of management problems. Van Dyne and Abramsky (1975) compiled a list of models used in agricultural and natural resource fields, including both simulation and optimization models. Weigert (1975) and Frenkiel and Goodall (1978) reviewed the development of simulation modeling and critiqued simulation model building. H. T. Odum (1971) and Holling (1978) presented modeling frameworks and several case examples. Potential users of simulation models need to critique carefully the assumptions underlying the simulation models. As Odum (1976) noted, no theoretical framework previously existed to guarantee the same structure in each ecosystem model.

Summary

The type of analytical technique used to determine the impact of management depends on the problem and the resources available. Where a diversity of management impacts or alternative sitings of one impact are examined, an intuitive approach, such as the ID team approach, has been found most useful (Cooper and Zedler 1980). Where one specific management activity or ecosystem is examined, a quantitative approach, such as simulation modeling, has been found useful (Hall and Day 1977).

ECONOMIC ANALYSES OF PRODUCTION

In economics, a large body of theory has been developed concerning production analysis. This section contains a brief review of the general theory of production and the use of mathematical programming in production analyses of resource outputs.

Economic Theory of Production

The economic theory of production deals with problems of allocation and utilization of limited resources by individual firms. Firms are considered to be technical units which transform inputs into outputs (i.e., engage in production). Inputs are anything the firm utilizes in producing outputs. Outputs are the commodities the firm produces.

Single Output Production

The production process that specifies the maximum output obtainable from any combination of inputs is said to be technically efficient. A mathematical expression that relates inputs and outputs through technically efficient production processes is called a production function, f , for a production process involving one output, Q , and inputs $I_1, \dots, I_n$.

$$Q = f(I_1, I_2, \dots, I_n) \quad [1]$$

Specific functional forms for f (both linear and non-linear) are used in empirical estimation of production functions.

Starting with the production function as given, economic production theory assumes that firms behave in an optimizing fashion, and focuses on decisions made by the firm with regard to optimal levels of inputs and outputs. In the simplest case addressed by production theory, firms are assumed to operate in competitive markets for both inputs and outputs (i.e., input and output prices are taken as constant by the firms for all levels of inputs and outputs). The case for other types of markets is also considered in classical production theory. For a general discussion of economic production theory, see a standard microeconomic text such as Henderson and Quandt (1971).

The firm may have to make three general production decisions. First, it may seek to maximize output, subject to a fixed budget with which to purchase inputs. Second, it may seek to minimize the cost of inputs, subject to producing a given level of output. Third, it may seek to maximize profits where both budget and output quantities are variable.

In the first two cases, the marginal condition for optimization with two inputs in equation [1] is:

$$\frac{\partial f / \partial I_1}{\partial f / \partial I_2} = RTS = \frac{C_1}{C_2} \quad [2]$$

where C_i = the factor price of the i^{th} input (I_i). The term on the left, the ratio of partial derivatives of the production function (which is the ratio of marginal products of the two inputs), is the rate of technical substitution (RTS). This ratio expresses the rate at which one input can be substituted for another in production and still obtain the same level of output. The term on the right is the ratio of input prices. The optimal level of production is found by equating the ratio of marginal products (RTS) to the ratio of input prices. This solution is shown graphically in figure 2.

In the third case, the more general problem faced by a firm is to maximize profits, allowing both budget and output levels to vary. Profit is equal to total revenue (PQ) less total cost ($C_1 I_1 + C_2 I_2$). By substituting equation [1] for Q in this expression of profit, the firm seeks to maximize:

$$\Pi = Pf(I_1, I_2) - C_1 I_1 - C_2 I_2. \quad [3]$$

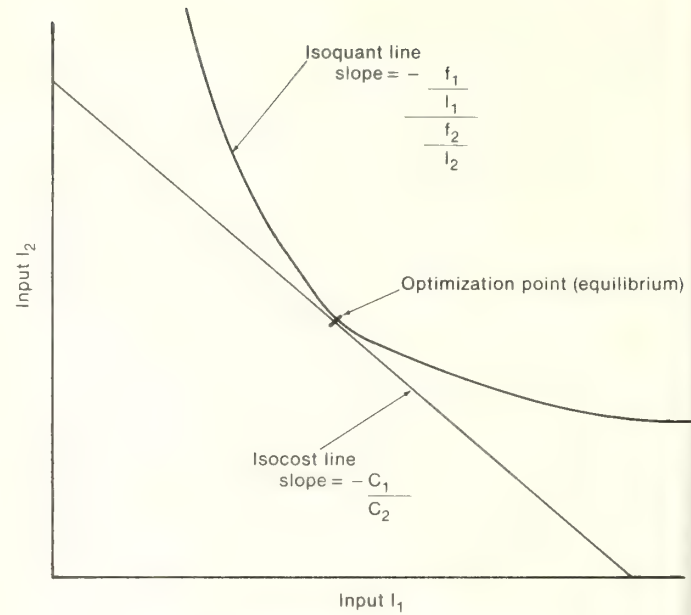


Figure 2.—Isoquant and isocost equilibrium.

Because the firm is a price taker in both the input and output markets, P , C_1 , and C_2 are constants. The marginal conditions for profit maximization are:

$$P \frac{\partial f}{\partial I_1} = C_1 \text{ and } P \frac{\partial f}{\partial I_2} = C_2 \quad [4]$$

On the left side of each equation, output price, P , is multiplied by the partial derivative of the production function (the marginal product). This term is the value marginal product (VMP) of input 1 or input 2. VMP shows the marginal rate of increase in revenue from using more of the given input. The terms on the right are input prices (C_1, C_2) and represent the rate of increase in total cost with additions of any input. The maximum profit level is found by equating the VMP of each input with that input's price.

Multiple Outputs and Joint Production

The general notation for multiple outputs and multiple inputs is given by an implicit production function:

$$f(Q_1, \dots, Q_m, I_1, \dots, I_n) = 0 \quad [5]$$

where Q and I are vectors of outputs and inputs, respectively. Joint production exists "... whenever the quantities of two or more outputs are technically interdependent.... The production of joint products does not require an extended analysis unless they can be produced in varying proportions. If two products are always produced in a fixed proportion... the analysis for a single output can be applied" (Henderson and Quandt 1971).

With fixed inputs, a product transformation curve or production frontier is implied, such as the one graphically portrayed in figure 3 for two outputs. The mar

ginal conditions for optimization in joint production for m outputs and n inputs require that:

1. the rate of product transformation between every pair of outputs must equal the output price ratio,
2. the rate of technical substitution between every pair of inputs must equal the input price ratio, and
3. the value marginal product of each input in production of each output must equal the input price.

Mathematical Programming

Mathematical programming is the term applied to a group of optimization techniques including linear programming, goal programming, integer and mixed integer programming, quadratic programming, geometric programming, and dynamic programming. All of these techniques are designed to select an optimal solution for a set of variables, often called activities. The optimal outcome is the numerical maximum or minimum of some specified performance criterion or objective function. This report will focus on linear programming as the state-of-the-art technique in applied mathematical programming, with a brief review of goal programming.

Linear Programming

Linear programming (LP) is a mathematical programming technique which can be used to maximize or minimize a linear objective function, subject to a set of linear constraints. A linear programming model has three major components:

1. The set of all possible activities under consideration. These are also called the choice variables, and make up the columns in the LP matrix, which is also called the A matrix.
2. The set of limitations on the resources needed to carry out the activities. These are called the con-

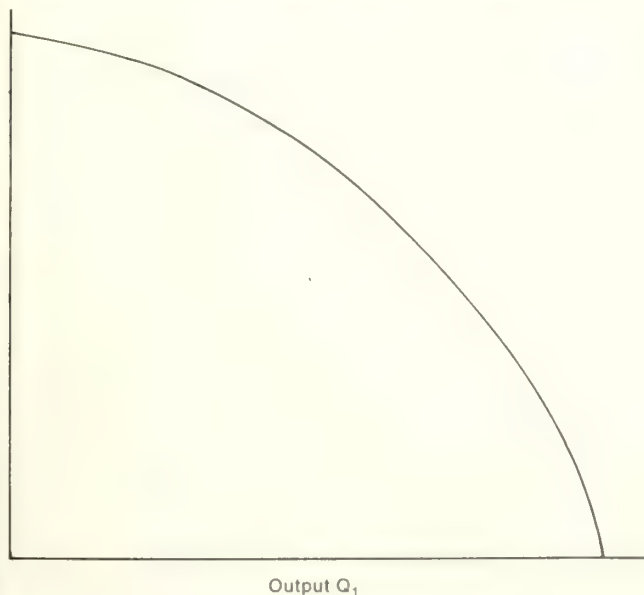


Figure 3.—Product transformation curve.

straints and, as linear combinations of the choice variables, make up the rows in the LP matrix. The sum of resources used by the activities must be constrained to the total resources available—often called the right-hand side or RHS.

3. The performance criterion for selecting the optimal set of activities from all possible activities. This objective function is a linear combination (weighted sum) of the choice variables, the weights being the numerical contribution of each to the objective function.

A simple representation of a linear programming problem follows:

Maximize:

$$Z = \sum_{j=1}^n C_j X_j \quad [6]$$

Subject to:

$$\sum_{j=1}^n A_{ij} X_j \leq B_i \quad i = 1 \dots m \quad [7]$$

$$X_j \geq 0 \quad j = 1 \dots n$$

In this example, there are n activities, and m constraints (rows). The total resource available for any row is B_i , and the amount of it used per unit of activity j is A_{ij} . Additionally, activities (X_j) may not take on a value less than zero. The problem expressed mathematically in equations [6] and [7] could be presented in matrix form in figure 4 for $n = 4$ and $m = 3$. The C_j are the objective function coefficients, indicating the marginal contribution of each X_j to Z .

X_1	X_2	X_3	X_4	type	RHS
A_{11}	A_{12}	A_{13}	A_{14}	$\leq$	B_1
A_{21}	A_{22}	A_{23}	A_{24}	$\leq$	B_2
A_{31}	A_{32}	A_{33}	A_{34}	$\leq$	B_3
C_1	C_2	C_3	C_4		Z
					(Maximize/ minimize)

Figure 4.—A matrix representation of an LP problem.

Several assumptions are necessary for the mathematical solution of a linear programming problem. First, all mathematical relationships in both the objective function and the constraints must be linear in the choice variables. Nonlinear relationships can be piecewise approximated with combinations of linear functions. Linearity is assured by two requirements—proportionality and additivity. Each activity's contribution to the objective function and its rate of resource use is proportional to that activity; that is, coefficients in both the objective

(C_i) and constraints (A_{ij}) are constant for all levels of activity X_j . The total contribution to the objective function and the total resource use of two or more activities engaged in at the same time must equal the sum of the individual contribution, or resource use, of each activity engaged in separately. Second, all choice variables must be nonnegative. Third, all choice variables must be divisible; that is, they can take on fractional values. Additional constraints may be imposed on choice variables to ensure an integer value in integer or mixed-integer programming, which require different solution techniques than the general linear programming problem. Fourth, all coefficients (C_i and A_{ij}) must be specified before the model is run. Additionally, it is assumed these coefficients are known with certainty; thus, LP is a deterministic model. Fifth, only one objective function may be specified for maximization or minimization at any one time.

Although the LP formulation in equations [6] and [7] implies a lack of a time dimension, this is not a general limitation of LP. Discrete time periods can be incorporated by adding additional rows and columns for each time period. In this way, the LP can both allocate and schedule the activity variables. For a very readable discussion of linear programming applied to resource planning see Kent (1980).

Linear Programming and Production Theory

A firm producing a single output may have several processes from which it can produce that output. A production process, represented by the columns in the LP matrix, utilizes the fixed resources (B_i) in some constant proportion (A_{ij}). This production process is of fixed proportions, divisible, and exhibits constant returns to scale (Dorfman, Samuelson, and Solow 1958). The firm chooses the optimal production process and the level of that production process. Because each process utilizes fixed resources at different but constant rates, substitution between sets of inputs can be accounted for by substitution between linear processes (i.e., between columns). A "kinked" isoquant results, as shown in figure 5 for two inputs (I_1, I_2).

Although the smooth marginal conditions found by calculus are not used in this "kinked" case, the same concepts of rates of substitution apply in the linear programming case. Substitution takes place between activities rather than directly between inputs.

The standard linear programming problem also can be interpreted for the case of joint production. Processes (columns) may exist for simultaneously producing more than one output. Because the resource level is fixed by the right-hand side, a production frontier can be traced out by allocating the available input to different processes and finding resultant output vectors. Such a production frontier is shown in figure 6 for two outputs. With this "kinked" production frontier, the concept of marginal rates of product transformation still apply to optimal decisions. In order to approximate the smoothly curved production frontier of production

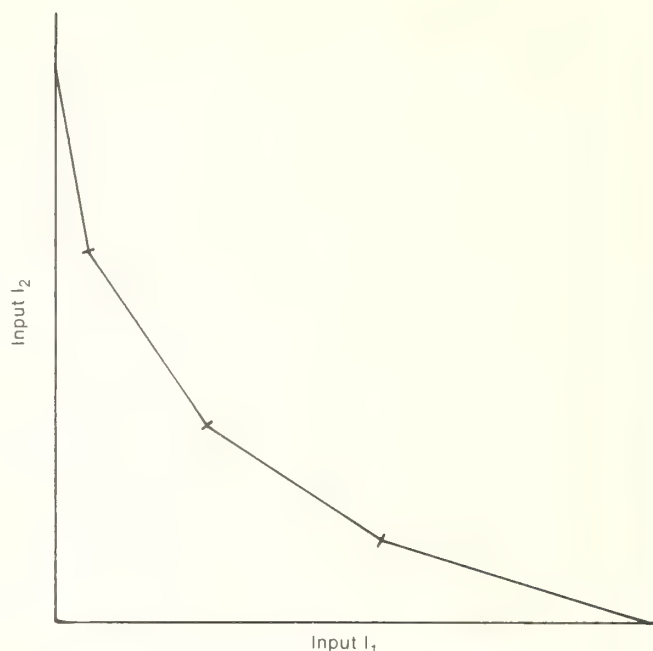


Figure 5.—Linear programming isoquant.



Figure 6.—Linear programming product transformation curve.

theory, it may be necessary to consider a large number of production process (i.e., a large number of columns in the LP matrix).

An important point is that linear programming generally starts one step before economic theory by choosing a technically efficient production process as well as an economically efficient one. In this sense, LP provides more information to a manager who is not aware in advance of technically efficient production processes. It can readily be used to show the implications of alternative choices. This aspect has made linear programming a widely used, practical tool for management and planning in the business sector.

History of Linear Programming Applications

Early Applications of Linear Programming to Forestry Problems

Some of the first applications of linear programming to forestry problems dealt with forest and wood industries. Paull and Walter (1955) and Paull (1956) applied linear programming to minimize delivery transportation costs and minimize trim loss in newsprint manufacturing. Bethel and Harrell (1957) used an LP to find optimum costs of alternative plywood production and distribution procedures. Jackson (1958) and Jackson and Smith (1961) used LP to determine optimal sawing methods in a mill. They formulated both a profit maximization and a production maximization problem.

Coutu and Ellertsen (1960) used LP to find the best (income maximizing) allocation of resources among various farming activities, including forestry. Some of the first scheduling applications dealt with minimizing the cost of providing pulpwood to a mill (Theiler 1959, Curtis 1962). The traditional forest regulation problem of maximizing volume subject to sustained yield constraints was formulated by Loucks in 1964. Kidd, Thompson, and Hoepner (1966) formulated the regulation problem to maximize present net worth subject to various management constraints. In 1967, Nautiyal and Pearse used LP to examine optimum harvest patterns, rotation length, and the conversion period.

In all of these early applications, the LP's were developed for each specific problem. In 1971, a linear programming package (Timber RAM) was developed which could be applied to various timber management planning problems (Navon 1971). For a more technical discussion of Timber RAM, see Alig et al. (1983). Prototype RAM models for range and transportation systems were developed later (Jansen 1976), but not widely used.

Although the inputs and outputs of Timber RAM are timber related, Navon (1971) suggested that the model could partially evaluate the "interaction of range, watershed, recreation, wildlife, and timber management policies." This was accomplished largely by excluding land from the allowable cut base and by meeting constraints imposed by commitments to produce other resources through reduction in wood yield.¹¹ Chappelle et al. (1976) argued that this approach to multiple-use considerations does not necessarily provide an optimal solution to forestry (as opposed to timber) planning problems.

This incremental approach to multiple-use modeling (i.e., starting with a timber model and then modifying it) appears to have precedent in the way functional planning evolved toward multiple-use planning in response to the Multiple Use-Sustained Yield Act of 1960. According to Hall (1963) multiple use was initially viewed as a problem of coordinating separate resource programs rather than starting with an overall multiple-use program. Hall suggests this approach can be explained by history:

¹¹Johnson, K. Norman. 1980. *Timber activity scheduling on the national forests: The second revolution*. Paper presented at Oregon State University seminar, Corvallis.

Forest managers have had long experience in planning for particular resources, especially timber. Multiple use objectives are currently being superimposed on the older procedures....foresters are accustomed to working with the traditional tools and concepts of timber management and probably the easiest way to obtain multiple use objectives is by building on this base.

Goal Programming

Goal programming is a mathematical programming technique that can be used to find a solution to a resource allocation problem involving several objectives, subject to a set of linear constraints. Depending on the type of formulation, all goals may be considered simultaneously in a composite (and single) objective function, or sequentially in a series of objective functions. Goal programming is a particular form of linear programming where the choice variables are deviational variables—showing over- or underachievement of the specified goal levels of output. For a more formal discussion of goal programming, see Lee (1972).

Goal programming concepts were developed by Charnes et al. in 1955 and applied widely to management problems in the business sector. Field (1973) introduced goal programming to the forestry literature. Bottoms and Bartlett (1975) applied goal programming to multiresource management of 9,050 acres of the Colorado State Forest. Their formulation used ordinal priority ranking of goals.

Bell (1976) further discussed transformation of a linear program into a goal program with a composite weighted objective function. Dane, Meador, and White (1977) used the composite weighted objective form of goal programming on a 158,000-acre planning unit on the Mt. Hood National Forest, Oregon. Schuler, Webster, and Meadows (1977) reported on their pilot application of goal programming on a 10,000-acre subunit of the Mark Twain National Forest, Missouri.

Schuler, Webster, and Meadows (1979) suggested the biggest problem in the application of goal programming involved the technical coefficients. Steuer and Schuler (1978), in a discussion of the same pilot study pointed out further problems, encountered in goal ranking:

The objectives [goals] were also ranked by the planning team. However, the ranking was strictly ordinal. A cardinal ranking scheme was considered to be unobtainable. This constituted the first noticeable beginning of the series of difficulties that occurred in trying to find an OR/MS technique to solve this forest management problem.

Dyer et al. (1979) used the Bottoms and Bartlett goal program to show the sensitivity of the goal programming allocation to changes in priority levels and concluded that an ordinal ranking goal programming would not solve the problem of determining objective function weights required to achieve a pareto optimum allocation of resources. Dyer et al. (1979) also discussed the use of goal programming as a suboptimization technique; they

concluded it is a useful tool if used carefully and with a complete understanding of its inner workings.

Linear Programming Multiresource Management Problems

INTEGRATED APPROACHES TO ANALYZING THE PRODUCTION OF NATURAL RESOURCES

A single theoretical basis for integrated analysis across disciplines does not exist today. Theoretical developments attempting to provide this theoretical basis include Georgescu-Roegen (1977), Boulding (1977), Thompson (1977), and Odum (1971). Odum (1978) uses energy to integrate ecological, economic, and social systems. Applications in regional planning can be found in Kemp et al. (1977) and Boynton et al. (1977). The difficulties of determining the value of energy in this approach have been discussed by Hyman (1980).

Holling (1978) developed an approach incorporating a quantitative description of system behavior using catastrophe theory, and a qualitative integration of system behavior using workshops. The workshops have been used to bring together the academicians, who mathematically describe the system, and the managers and politicians, who manage the system. The feedback between managers, politicians, and academicians facilitated a deeper understanding of the system and its model. Applications in land planning can be found in Holling (1978).

The dominant technique in integrating ecological and economic analyses is the optimization modeling approach. These models can analyze the tradeoffs between a variety of resource production alternatives. The decision criteria for the tradeoff analysis can be varied also. This type of analysis presumes the input of benefit/cost information and production capability/response information.

Perhaps the most successful applied attempts at integrating information across disciplines and resources have been the multiresource linear programming models. The first example of such a model was D'Aquino (1974). The basic structure of these models will be illustrated in a simplified linear programming model considering only two types of land, five management prescriptions, and three resources (fig. 7).

In figure 7, the major column headings are types of land and/or resources. The " X_i 's" under the two land types are the number of acres allocated to alternative management prescriptions which could be applied in TYPE I (X_1 and X_2) and TYPE II (X_3 , X_4 , X_5) land. X_1 through X_5 are choice variables defined as the number of acres allocated to the given management prescription (1 through 5).

The timber, wildlife, and forage rows in the matrix represent the resource outputs of this forest system which result from implementation of the management prescriptions. The land, TYPE I and TYPE II, rows are the inputs (acres) to this joint production system. K_5 acres of Type I land are available, and K_6 acres of Type II land are available.

The timber output, wildlife output, and forage output rows are the amounts of each of the outputs that are harvested from the forest system. The "Net Benefit" row is the objective which managers seek to maximize given the resources available and the production relationships involved.

The " X 's" under the major column heading "Products" (X_6 , X_7 , X_8) are accounting columns which collect

	Type I		Type II			Products			Constraint type	RHS
	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8		
Timber	$A_{1,1}$	$A_{1,2}$	$A_{1,3}$	$A_{1,4}$	$A_{1,5}$	$-A_{1,6}$			=	$K_1 = 0$
Wildlife	$A_{2,1}$	$A_{2,2}$	$A_{2,3}$	$A_{2,4}$	$A_{2,5}$		$-A_{2,7}$		=	$K_2 = 0$
Forage	$A_{3,1}$	$A_{3,2}$	$A_{3,3}$	$A_{3,4}$	$A_{3,5}$			$-A_{3,8}$	=	$K_3 = 0$
Budget	$A_{4,1}$	$A_{4,2}$	$A_{4,3}$	$A_{4,4}$	$A_{4,5}$				≤	K_4
Type I	$A_{5,1}$	$A_{5,2}$							=	K_5
Type II			$A_{6,3}$	$A_{6,4}$	$A_{6,5}$				=	K_6
Timber output						$A_{7,6}$			≥	K_7
Wildlife output							$A_{8,7}$		≥	K_8
Forage output								$A_{9,8}$	≥	K_9
Net Ben.	$A_{10,1}$	$A_{10,2}$	$A_{10,3}$	$A_{10,4}$	$A_{10,5}$	$A_{10,6}$	$A_{10,7}$	$A_{10,8}$		

Figure 7.—A simple resource allocation model where X_1 and X_2 are the number of acres in Type I land allocated to alternative management prescriptions; X_3 , X_4 , X_5 are the number of acres in Type II land allocated to alternative management prescriptions; X_6 , X_7 , X_8 are timber, wildlife, and forage products, respectively; the A_i are production coefficients; the $A_{10,i}$ are the objective function coefficients; and the K_i are the right-hand sides (RHS).

or transform the outputs described in some of the rows into an aggregate output for the area being analyzed.¹²

The A_{ij} 's in columns one through five can generally be termed the impacts of the j^{th} management prescription on either the row outputs or row inputs. For example, $A_{1,1}$ is the output of timber per acre if the first management prescription is implemented, and $A_{5,1}$ is the amount of Type I land it takes to implement the minimum size prescription 1 treatment.

The coefficients in row 10, the "Net Benefits" row, describe the change in net benefits if one unit of the i^{th} management prescription occurs. Thus, $A_{10,1}$ is the cost of prescription 1 and $A_{10,6}$ is the benefit derived from one unit of timber output (X_6).

K_4 is an upper limit on the amount of money to be made available for managing the area. K_7 through K_9 are minimum levels of timber, wildlife, and forage that are required.

This simple model ignores time dimensions and other complexities such as nonconstant benefit coefficients. Environmental quality indexes are also excluded from the example. These complexities do not pose severe analytic problems, and they can be brought into the analysis without conceptual difficulty—though such a model would be significantly larger (i.e., more rows and columns).

Multiresource Models

The CARD-USDA Agricultural LP Model

Linear programming models are well suited to evaluating the response of agricultural production to changing policy or economic perturbation on both an intraregional and interregional basis. A model designed to do this has been constructed and tested by the Center for Agricultural and Rural Development (CARD) at Iowa State University in cooperation with USDA Soil Conservation Service and the USDA Economics, Statistics, and Cooperatives Service.

Given regional and national demands for land, water, fertilizer, and pasture, together with the quantity of resources available for use in satisfying them (i.e., constraints), the CARD-USDA model can minimize the cost of producing those demands. As such, the model can be used to assess the effects of initiating new markets, changing demands and resource availabilities, modulating costs, and altering the interaction of commodity production, resource purchase, and land development activities with the relevant markets.

The CARD-USDA model was delineated regionally in several ways. On the basis of soil type and management attributes, 164 land resource regions were defined. On the basis of production (crops and water) 105 separate producing areas were defined. Additionally, producing areas were agglomerated into 28 major marketing regions with a market center defined for each. Transfers of resources and demands between regions were at the marketing region level.

¹² K_1 through K_3 are set at zero to force all product output levels into X_6 , X_7 , and X_8 .

RCS-RAA

In 1972, a system of interrelated computer programs was developed by the USDA Forest Service Watershed Systems Development Unit in Berkeley, Calif. The Resources Capability System (RCS) was designed to be "used to quantitatively evaluate functional programs as they relate to the basic soil, climatic, and water resources. This information can then be combined in the system with quantitative data from the various disciplines and functions of resource management, plus selected management objectives and constraints, and utilized in an interdisciplinary analysis of resource allocation alternatives" (USDA Forest Service 1972).

The Resources Capability System included several response simulation models (water yield, sediment yield, individual renewable resource models, and an economic analysis model) and a multiple resource allocation model. This allocation model became known as the Resource Allocation Analysis (RAA) component. It was this RAA component of RCS which received most of the attention during the mid-1970's. It included an LP model, its associated A-matrix generator, and its output display programs.

The RAA was first applied to water resource and river basin development planning. By 1975, it had been used on approximately 40 land-use planning problems in the USDA Forest Service National Forest System. Most of the forests using the RAA for multiple-use planning were in the West (Beaverhead, Nezperce, Montana; Willamette, Oregon; Modoc, Klamath, Shasta Trinity, California; and Payette, Idaho). The set of computer programs was continually modified in response to user needs in these various applications (Lundeen 1975).

The matrix generator, called MAGE5, was perhaps the most unique and notable aspect of the RAA package. A versatile, user-specified model, it included delineation of constraints, costs, benefits, and a single objective function. The output of goods and services could also be time-streamed; that is, outputs resulting from the application of management prescriptions could vary over time. The same could occur for rates of capital and labor inputs pertaining to resource management. In addition to the time-streaming option, the production of timber could be simulated with a user-specified growth function. This was one of the first examples of a coupling between simulation and optimization models even though the former was self-contained in the latter. The developers had planned to provide for additional simulation models as a way to quantitatively describe resource interactions; however, this was not fully accomplished.

The specification of the objective function in RAA allowed for flexibility. The user could specify any of the commodity or economic rows (or any combination of them) as an objective function (Lundeen 1975). Although it was possible to minimize costs, the most commonly used approach was to maximize present net worth or one of the major commodities. The LP was designed to be run iteratively with changing objective functions or different right-hand side constraints.

Overall, the RAA was user-operated and controlled. For example, the three main components of RAA (LP

model, matrix generator, report writer) could either be operated as a sequential, interfaced system, or as separate programs in order to aid in accomplishing other RCS objectives. Additional information on RCS can be found in USDA Forest Service (1972) and Dyrlund (1973).

FREPAS

The FREPAS (Forest-Range Environmental Production Analytical System) model was developed as part of the Forest-Range Environmental Study (FRES), during 1970-72. The purpose of this study was to collate information about United States rangelands and to develop a technology for evaluating such information in a way that would serve the planning needs of the USDA Forest Service (USDA Forest Service 1972b). The analytical system was to permit the manipulation of various economic, political, and social constraints on the use of different range resource units in order to determine optimal management procedures.

The FRES model was a multiresource LP model with a cost-minimization objective function. Required model inputs included a nation-wide forest and range land inventory. For each land unit, the following inputs are required: then current (1970) management strategies, and associated resource outputs, maximum potential of resource production, and minimum level of management for each land unit based on legal restrictions. The data base for these inputs was developed as part of the FRES study. Computer programs for data manipulation, matrix manipulation, LP solution, and a report writer were developed (Kaiser et al. 1972). The FRES model was run under a series of policy alternatives (e.g., budget and resource production constraints), and the results, in terms of resource outputs, were compared with the then current (1970) situation (USDA Forest Service 1972b).

FRES defined a framework for land inventory. Thirty-four soil-vegetation units, based on Kuchler's (1964) classification system of potential natural vegetation, formed the foundation for land classification across the 48 coterminous states (Garrison et al. 1977). Each soil-vegetation unit, or ecosystem, was further divided by productivity (four classes) and condition (three classes). On forest ecosystems, productivity was defined by capacity to produce wood, and condition was defined by the stocking level of poles and sawtimber. On nonforest ecosystems, productivity classes were assigned according to relative herbage production compared to the maximum potential of that ecosystem. Condition classes followed the concepts supporting the USDA Forest Service definition of range condition (i.e., vegetative composition and vigor, soil erosion, and erosion-potential factors).

In addition to partitioning on the basis of potential vegetation, production, and condition, land was further divided according to ownership. Three ownership categories were recognized: (1) National Forest System, (2) other federal, and (3) nonfederal. As a result of the above partitioning, 1,224 unique combinations (called resource units) of ecosystem-productivity-condition-

ownership were possible. Of these, the task force obtained and evaluated data for 956 resource units (USDA Forest Service 1972b).

The resource output production under different management strategies for each resource unit was determined by an interdisciplinary team of scientists. For each of six possible management strategies (table 1), a set of management practices were generated by the team. Resource outputs for each resource unit for each management strategy were also estimated by the team (table 2).

Table 1.—Management Strategies in FREPAS (USDA Forest Service 1972b)

Strategy A—Environmental management without livestock. Livestock are excluded by fencing, riding, public education, or incentive payments. Damage to the range resource is corrected to maintain a stewardship base. The range management cost is borne by other functions, such as timber.
Strategy B—Environmental management with livestock. Livestock is permitted at present capacity of the range environment. Investments are made only to maintain the environment at a stewardship level. Costs of correcting past abuse are charged to other functions.
Strategy C—Extensive management of environment and livestock. Management seeks full utilization of the animal unit months available for grazing. However, no attempt is made to maximize forage production by cultural practices.
Strategy D—Intensive management of environment and livestock. Production of forage is maximized subject to the constraints of multiple use. This strategy includes reseeding and complex livestock-management systems and practices.
Strategy E—Maximum management of environment and livestock. Livestock production is maximized, subject only to stewardship of soil and water resources. Multiple use is not a constraint.
Strategy X—Management at a substewardship level. Livestock are grazed at a level that depletes the range resource.

Table 2.—Resource outputs estimated for each resource unit in the FRES study (USDA Forest Service 1972b)

Output	Unit of measure
Grazing measures	
Browse and herbage	Tons per acre per year
Animal unit months	AUM per acre per year
Animal output value	\$ per acre per year
Joint products	
Wood	Cubic feet per acre per year
Water	Acre feet per acre per year
Water quality	Acre feet per acre per year
Storm runoff	Inches per acre per year
Sediment	Tons per acre per year
Employment	Man hours per acre per year
Qualitative estimates	
Soil stability	A value between 1-5
Rare and endangered species	A value between 1-5
Nongame birds	A value between 1-5
Carnivores and raptors	A value between 1-5
Air quality	A value between 1-5
Soil quality	A value between 1-5
Depressed area impact	A value between 1-5
Cultural heritage, resident	A value between 1-5
Cultural heritage, nonresident	A value between 1-5
Beauty	A value between 1-5

¹A 5-point scale was used to measure qualitative products. The five points were: 1 = bad, 2 = poor, 3 = fair, 4 = good, and 5 = excellent.

FREPAS, as an LP model, allocated acres of land to the various management strategies within each resource unit, subject to given resource product constraints, in order to minimize the investment cost for range management and treatment (Kaiser et al. 1972). The FREPAS model assumed a static environment, and did not allow for scheduling (i.e., the model ignored the effects of a decision's impact on opportunities during subsequent time periods).

NIMRUM

The National Interregional Multiresource Use Model (NIMRUM) is one of the four models in the National Interregional Multiresource Analytical System (NIMRAS) which was developed for the 1980 RPA Assessment. The purpose of NIMRAS was to help evaluate alternative national programs of forest and range land management. The models were summarized by Ashton et al. (1980) as follows:

The National Interregional Multiresource Use Model uses linear programming to allocate national and regional demands for renewable resource uses on the land base. This model minimizes operational costs of alternative programs while achieving environmental restraints, range production, sustained wood yield, and wilderness.

The second model evaluates regional employment and earnings triggered by a national program.

The third model, Futures Foregone, keeps count of future options lost in terms of the amount affecting citizens groups, rate of impact, and length of impact.

The last model, Social Conflict, operates on the postulate that there will be proponents and opponents for any resource use and that some degree of conflict is inevitable. The model uses impact information including that generated from previous models and serves to quantify the amount and pattern of conflict.

NIMRUM is a linear programming model which seeks to minimize the cost of allocating the nation's forest and range land base to alternative resource management activities, so as to meet expected demands for the various outputs. Ashton et al. (1980) explained NIMRUM this way:

Each allocation is a pattern of resource uses that satisfies demand projections for certain market and nonmarket outputs. In this sense, the demand for goods and services is the driving force of the model. Costs are calculated for each allocation, and these direct the model toward its goal, the selection of the least expensive resource allocation, and management pattern to meet demand.

NIMRUM was the first national-level land allocation model to account internally for resource interaction (joint production). Because of the size of the national model, computations were actually carried out on two subnational models—one for the East and one for the West.

The NIMRUM land base was stratified according to 107 Kuchler potential natural communities (PNC), four

ownership categories, four productivity categories, and four condition classes. The ownership categories were: National Forest System lands (NFS), Bureau of Land Management lands, other federal lands, and state and private lands. There were four productivity and four condition classes. As a result of the above partitioning, approximately 5,000 unique combinations (Resource Units) of ecosystem-productivity-condition-ownership were possible. These Resource Units (RU) were assumed to exhibit homogeneous response to management.

For each RU, the resource outputs under different management were determined by an interdisciplinary team of scientists. In FREPAS, only management strategies associated with range were defined (table 1). In NIMRAS, appropriate combinations of management levels for range, wildlife, and timber representing current use were made by the ID team for each RU. Thus, for example, a combined management level to "do nothing" consists of: range management A—environmental management without livestock; timber management level 1—no commercial use; and wildlife management level 1—no management. Each combination, called a management triplet, had a set of management practices associated with it. Six management levels, similar to the six strategies in FREPAS, were possible for range. Six management levels for timber and three management levels for wildlife were defined. Table 3 lists the resource outputs in NIMRUM.

Table 3.—Resource outputs in the NIMRUM model
(Ashton et al. 1980)

Output	Unit of measure
Herbage and browse production	Pounds per acre per year
Net wood growth	Cubic feet per acre per year
Wood harvested	Cubic feet per acre per year
Domestic livestock grazing	AUM per acre per year
Wild ruminant grazing	AUM per acre per year
Dispersed recreation use	Visitor-day per acre per year
Water yield	Inches per acre per year
Storm runoff	Inches per acre per year
Sediment yield	Tons per acre per year
Life form—water	Percent of area
Life form—ground	Percent of area
Life form—bushes	Percent of area
Life form—trees	Percent of area

Resource management practices are the basis for NIMRUM costs. Costs of the individual resource management practices were aggregated into single resource management levels, and the cost of the management level for timber, for range, and for wildlife were added to generate total costs for the management triplet. Costs for all ownerships were assumed to be similar. Range costs were based on Forest Service budget data, and timber costs were based on the Forest Service Timber Management Practice Cost Survey conducted in 1976. Wildlife costs were drawn from timber or range costs, depending on the type of vegetation manipulation undertaken for habitat management. All costs were annual averages based on a 50-year time period. Capital costs

(consisting chiefly of roads) with relatively long lives were discounted at 6-5/8%. Other costs were not discounted.

Pickens¹³ noted that the objections to NIMRAS were the result of a lack of faith in the input data. While he acknowledged that there are problems with the data, the use of an ID team to generate such a national data set was considered the most viable approach to give the best possible data with the time and resource constraints imposed on the development of NIMRAS. Some of the information required in the analysis was not available from scientifically conducted studies, reflecting the functional approaches taken in previous studies on management implications. He stressed that, for NIMRAS, the data was sufficiently accurate to measure the type of responses they were commissioned to study. Further uses of the model should examine the data quality problem.

FORPLAN

The Forest Planning Model (FORPLAN) is intended for use on every national forest (or groups of national forests) in the USDA Forest Service National Forest System. It is one of the analytical tools to be utilized in fulfilling the requirements of the National Forest Management Act of 1976 and its subsequent regulations.

FORPLAN is a software package that serves as a matrix generator, an interface to the Univac 1100 FMPS¹⁴ linear programming (LP) solution algorithm, and a report writer of the LP solution. The type of LP which FORPLAN creates varies considerably according to application by the user on any given forest. Many options are available in the FORPLAN package—a characteristic that is consistent with the widespread application intended. In general, the LP which FORPLAN generates is intended to simultaneously solve management activity scheduling problems, land allocation problems, and output mix problems. The basic structure is much like the simple example given previously, with the addition of scheduling capabilities. Because FORPLAN evolved from a timber model called MUSYC, it retains some emphasis on timber analysis capabilities; however, the emphasis in application is up to the user rather than the software package itself.

The responsibility for determining alternative management prescriptions to be applied within the forest and for quantifying the ecological impact of those management prescriptions rests with the interdisciplinary team (ID team). Because this information is forest-specific, the experience of the team members on site becomes very important. In order to present the general flavor of FORPLAN capabilities, some of its more important options/characteristics are briefly discussed in this

section. For a comprehensive discussion of FORPLAN, see Johnson et al.¹⁵

Perhaps most basic to the configuration of any LP generated by FORPLAN is the definition of analysis areas (AA's), analogous to RU's in NIMRUM, and the alternative management prescriptions for each analysis area. FORPLAN allows considerable flexibility in the user designation of analysis areas and management prescriptions. Analysis areas are identified by three user-specified land characteristics (up to 60 categories of each), up to 9 working groups, up to 15 land classes, and up to 60 existing vegetation classes. Every alternative management prescription specified in FORPLAN must apply to a given analysis area. In addition, alternative prescriptions can be included to apply to the regeneration classes created by prescriptions with harvest practices. The time frame that applies to management prescriptions as well as to resultant outputs is also quite variable, having up to 30 time periods of 1 to 20 years each.

Also basic to the structure of any LP generated by FORPLAN is an option called "Aggregate Emphasis." This option allows designation of groups of analysis areas that must be allocated to management prescriptions together. This restriction is to avoid illogical situations such as "an analysis area allocated to intensive timber management production in the midst of analysis areas allocated to a wilderness".¹⁵

The structure of any FORPLAN-generated LP is also subject to area and volume control, harvest flow (e.g., nondeclining yield), ending inventory, management emphasis and intensity, and cultural treatment constraints. These kinds of constraints can take on numerous configurations.

Concerning timber harvest (and other timber activity) scheduling, FORPLAN can construct an LP based on either of two structures (Johnson and Schnerman 1977) which differ in the manner in which they define timber choice variables and handle multiple harvests within the planning horizon. Model I is more conducive to keeping track of location on the ground, while Model II is more conducive to minimizing model size.

FORPLAN has options for 10 different objective functions in the LP it generates:

1. Maximize PNW for n periods—maximize discounted present net worth (net monetary income) over n periods under the assumption that the amount of output provided does not affect its price.
2. Minimize cost for n periods—minimize undiscounted monetary cost over n periods.
3. Minimize discounted cost for n periods—minimize discounted monetary cost over n periods.
4. Maximize PNW under downward-sloping demand for n periods—maximize discounted net income over n periods under the assumption that the amount of output offered influences the price received.

¹³Pickens, James B. 1980. *NIMRAS system documentation*. (Unpublished report prepared for USDA Forest Service, Washington, D.C.).

¹⁴The use of trade and company names is for the benefit of the reader; such use does not constitute an official endorsement or approval of any service or product by the U.S. Department of Agriculture to the exclusion of others that may be suitable.

¹⁵Johnson, K. Norman, Daniel B. Jones, and Brian M. Kent. 1980. *Forest planning model (FORPLAN) user's guide and operations manual*. (Draft). USDA Forest Service Land Management Planning, Fort Collins, Colo.

5. Maximize PNB under downward-sloping demand for n periods—maximize discounted net benefit (approximately the discounted sum of producer's plus consumer's surplus) over n periods, under the assumption that the amount of output influences the price received.
6. Minimize deviations from goals—minimize the penalty incurred through nonachievement of the goals specified.
7. Maximize output i for n periods—maximize one of the scheduled or nonscheduled outputs over n periods.
8. Minimize output i for n periods—minimize one of the scheduled or nonscheduled outputs over n periods.
9. Maximize PNW for individual stands—specifying this objective function produces a report giving the maximum discounted net income (PNW) over the planning horizon projected for each analysis area containing timber available for harvest, considering each prescription and possible time of entry and harvest.
10. Maximize PNW for individual stand with detail—specifying this objective function produces a report giving the maximum PNW for each analysis area containing timber available for harvest, as done under objective 9. It also produces the PNW for each prescription designated for each analysis area, considering all possible times of entry and harvest.

For objective functions 4 and 5, FORPLAN can generate a piecewise approximated downward-sloping demand curve for timber. Fixed prices are assumed for all other outputs. At this time, costs can be assigned per acre for timber-related management prescriptions and per unit output for all outputs (including timber). It is anticipated that the capability to assign costs per acre for all management prescriptions will soon be available in FORPLAN. An option to include fixed costs is also available in FORPLAN.

Output constraints or output targets are an important part of the LP models generally developed with FORPLAN. These targets set minimum or maximum levels of outputs to be obtained in the LP solution and literally drive the model in some instances. Inclusion of these targets is directly mandated by the NFMA regulations.

CONCLUSIONS

Optimization models provide a method to integrate the ecological, economic, and social impact analyses, and to identify opportunities based on selected criteria. The predictions from simulation models can be used as input for the optimization model. Specifically, the supply/demand models can provide the benefit/cost (economic) information, and the ecological analyses can provide the production capability/response information for the optimization models. The social analyses can predict social impacts of the solutions provided by an optimization model. Public participation also provides social in-

puts. In integrating ecological, economic, and social analyses, optimization models can analyze tradeoffs between resource outputs and opportunities for improving the resource situation based on a variety of criteria.

The difficulty of scope remains, however. Modeling relatively small areas of land (such as a National Forest) is appealing because of the relative detail, resolution, and accuracy that can be achieved. However, regional and national concerns are different than local concerns and joint strategies between small land units may be highly desirable. The need for centralized decisionmaking is a primary motivation for national planning efforts such as RPA.

There are essentially three alternative approaches to this dilemma. First, a national model could be utilized, capturing whatever level of resolution possible. This is roughly the approach taken in the NIMRUM effort. Second, one could simply "add up" the results of small-scale models, such as FORPLAN. Third, a middle-ground solution would be a multilevel approach as outlined by Wong (1980).

Basically, the idea is to utilize models such as FORPLAN at the lowest levels of analysis and analyze only alternative output vectors at higher levels. That is, all production possibilities analysis occurs only at the lowest level, and the higher level models simply "choose" from the different possibilities that are determined to be feasible. This type of approach is discussed elsewhere in more detail as a possible assessment analysis tool.¹⁶

¹⁶U.S. Department of Agriculture, Forest Service. 1981. *Problem analysis: Integrated resource analysis for national assessments*. 150 p. Staff paper—National Resource Analysis Techniques Project, Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

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This paper gives an overview of the analytical methods that have been used in integrated (multidisciplinary, multiresource, and multilevel) land management production analyses. The ecological and economic theory underlying both simulation and optimization methods are also reviewed.

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Rocky
Mountains



Southwest



Great
Plains

U.S. Department of Agriculture
Forest Service

Rocky Mountain Forest and Range Experiment Station

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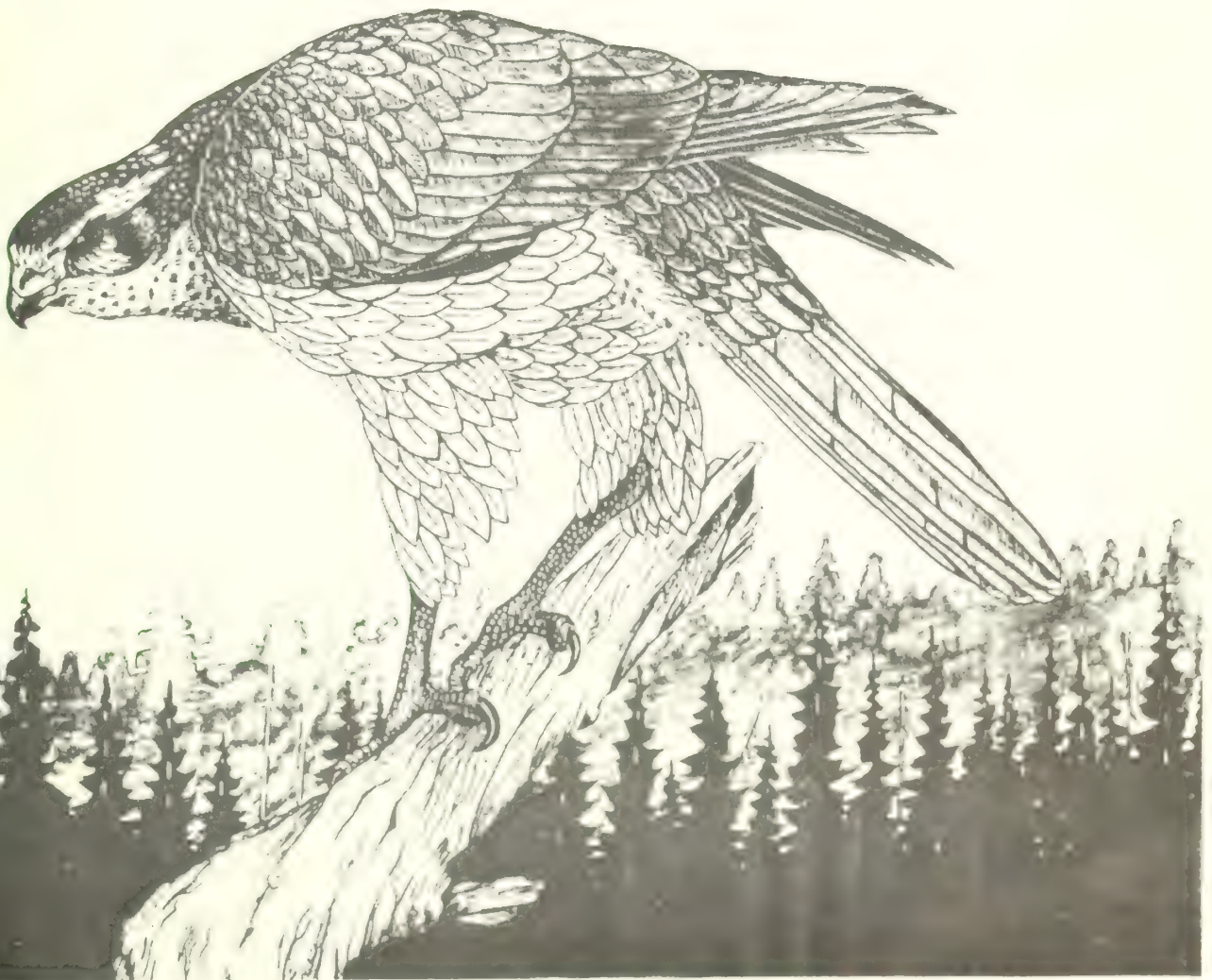
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General Technical
Report RM-102

Management of Western Coniferous Forest Habitat for Nesting Accipiter Hawks

Richard T. Reynolds



Management of Western Coniferous Forest Habitat for Nesting Accipiter Hawks

Richard T. Reynolds
Rocky Mountain Forest and Range Experiment Station¹

Abstract

Availability of nesting sites can limit accipiter populations. Because accipiters nest in dense forest stands, any alteration that opens these stands is likely to lessen their desirability as nest sites. Tree growth and the associated changes in the vegetative structure of aging nest sites limit the number of years sites will be suitable. Therefore, prospective replacement sites should be selected within the core areas of home ranges before precommercial and commercial harvesting begins.

¹Headquarters is in Fort Collins, in cooperation with Colorado State University.

Management of Western Coniferous Forest Habitat for Nesting Accipiter Hawks

Richard T. Reynolds

Management Implications

The sharp-shinned hawk (*Accipiter striatus*), the Cooper's hawk (*A. cooperii*), and the northern goshawk (*A. gentilis*), have such specific nesting habitat requirements that they are vulnerable to changes in forest stands resulting from timber harvesting. To maintain populations of these species in western conifer forests, the following recommendations² are proposed:

1. Uncut areas of approximately 4, 6, and 8 ha should be left around active nests for the sharp-shinned, Cooper's, and goshawk, respectively.
2. Because of tree growth and associated changes in the vegetative structure of nest sites, management of accipiter habitat must consider the turn-over of nest sites. Prospective replacement nest sites within the home range of each pair should be selected and managed accordingly.

3. Active and prospective nest sites should not be precommercially or commercially thinned, because this will result in reduced stand densities and deeper tree crowns.

4. To maintain nesting densities of the three *Accipiter* species equal to that found in Oregon, currently suitable nest sites should be provided at the following approximate densities: 20 sites per township (36 square miles, 9,324 ha) for sharp-shinned hawks, 5 per township for Cooper's hawks, and 4 per township for goshawks.

5. Further study should be oriented towards: (1) estimating the density of these species in other localities where forestry is changing the structure of forest stands, (2) confirming the suggested size and shape of uncut areas around nest sites, and (3) determining, with telemetry, the size and shape of home ranges, the types of habitats included within ranges, and the extent to which these habitats are used for foraging by these hawks.

Introduction

Reynolds (1979) and Reynolds et al. (1982) have shown that sharp-shinned hawks, Cooper's hawks, and goshawks in Oregon have specific nesting habitat requirements. They also found that this specificity makes breeding accipiter populations vulnerable to some forest management practices. Precommercial and commercial thinning decrease nesting habitat for the first two species; harvesting of mature forests decreases goshawk nesting habitat. If forest managers are to minimize the impacts of timber management on these species, they need: (1) an estimate of the number of nest sites required to maintain populations of each species in large areas, (2) to identify specific nesting habitats for accipiters, and (3) to include management of these sites in forest management plans.

The findings of Reynolds and Wight (1978), Reynolds (1979) and Reynolds et al. (1982) on the density of nesting pairs, the vegetative and physiographic structure of nest sites, and the within-season and annual patterns of use of a site by pairs of accipiters in Oregon are summarized here. Estimates of home range size and movements of the North American accipiter during

breeding are reviewed and compared with some reliable estimates of size of home range for European accipiter. Finally, some recommendations on management of accipiter habitat are presented.

This paper presents a habitat management scheme that accounts for the intermixture and dispersion of nesting sites for each species as well as for the turnover of nest sites resulting from stand growth and associated changes of the vegetative structure. This scheme should provide land managers with the tools to: (1) identify active and potentially active nest sites; (2) produce and maintain the important structural elements within sites; and (3) distribute suitable nesting habitat over time and geographic area.

Although this research was done in Oregon, the underlying concepts and accipiter nesting behavior should be comparable throughout the western coniferous forests. Reports in the literature from the western United States and the preliminary findings of habitat studies of these species in Colorado support this contention.

Methods

Nests were surveyed during the nesting seasons (April through August) from 1969 through 1979. Aerial photographs (scale = 1:12,000 to 1:24,000) and topographical maps (1:24,000) were used to locate potential nest sites on the basis of topography and stand density (Reynolds 1982). To ensure an accurate determination of

²The research upon which these recommendations are based was conducted under the auspices of the Oregon Cooperative Wildlife Research Unit: Oregon Department of Fish and Wildlife, Oregon State University, U.S. Fish and Wildlife Service, and the Wildlife Management Institute cooperating. It was funded in part by the Oregon Cooperative Wildlife Research Unit and USDA Forest Service, Pacific Northwest Forest and Range Experiment Station.

the density of pairs of each species, two large, forested study areas (9,284 and 11,741 ha) were intensively searched for nests (fig. 1). Distance between nests of conspecifics was measured; because some pairs used alternate nest sites in different years, these distances were calculated yearly.

The methods used to quantify the vegetative and physiographic structure of nest sites are described by Reynolds et al. (1982). The vegetation sampling was designed so that the entire stand containing the nest tree could be characterized. Nest-site use patterns were determined by observations from blinds in the early nesting season and from locations of plucked prey, molted feathers, and accumulation of feces. Various behaviors were observed during visits to nest sites throughout the nesting period. Nest-site use patterns between two or more alternate sites were determined by following pairs through three to five breeding seasons (Reynolds and Wight 1978).

Nest Density and Spacing

Nests of each *Accipiter* species were found from near sea-level to near timberline. In the intensively searched study areas, nest densities were one goshawk nest per 2,750 ha, one Cooper's hawk nest per 1,992 ha, and one sharp-shinned hawk nest per 2,750 ha. Because of edge effect, however, these figures are only rough estimates of density. Home ranges of these species are large enough to make it probable that a study boundary would cut off portions of one or more range. Therefore, the size

of these study areas could have been changed with little or no change in the number of nests included within the boundaries.

Distances between nests provide another estimate of density. The combined (years and study areas) mean nearest neighbor distances between nests of conspecifics were 5.6 km (range, 2.4 – 8.4 km) for goshawks, 4.7 km (range, 2.6 – 6.9 km) for Cooper's hawks, and 4.1 km (range, 1.8 – 6.0 km) for sharp-shinned hawks (Reynolds and Wight 1978).

Nesting Chronology

Goshawks and Cooper's hawks usually appeared in their nest sites in late March; sharp-shinned hawks arrived in late April. Mean clutch completion dates were May 6 for goshawks, May 14 for Cooper's hawks, and May 26 for sharp-shinned hawks. Date of nesting did not vary much with elevation. For each species, incubation lasted approximately 30-32 days. Young fledged about 36 days after hatching for goshawks, 29 days for Cooper's hawks, and 23 days for sharp-shinned hawks. After fledging, the young were fed by the adults, and remained in the vicinity of the nest for 30-50 days.

Nest Sites

Accipiter "nest sites" are defined as the forest stand containing the nest tree, including both the structural features of the vegetation (e.g., tree density, canopy

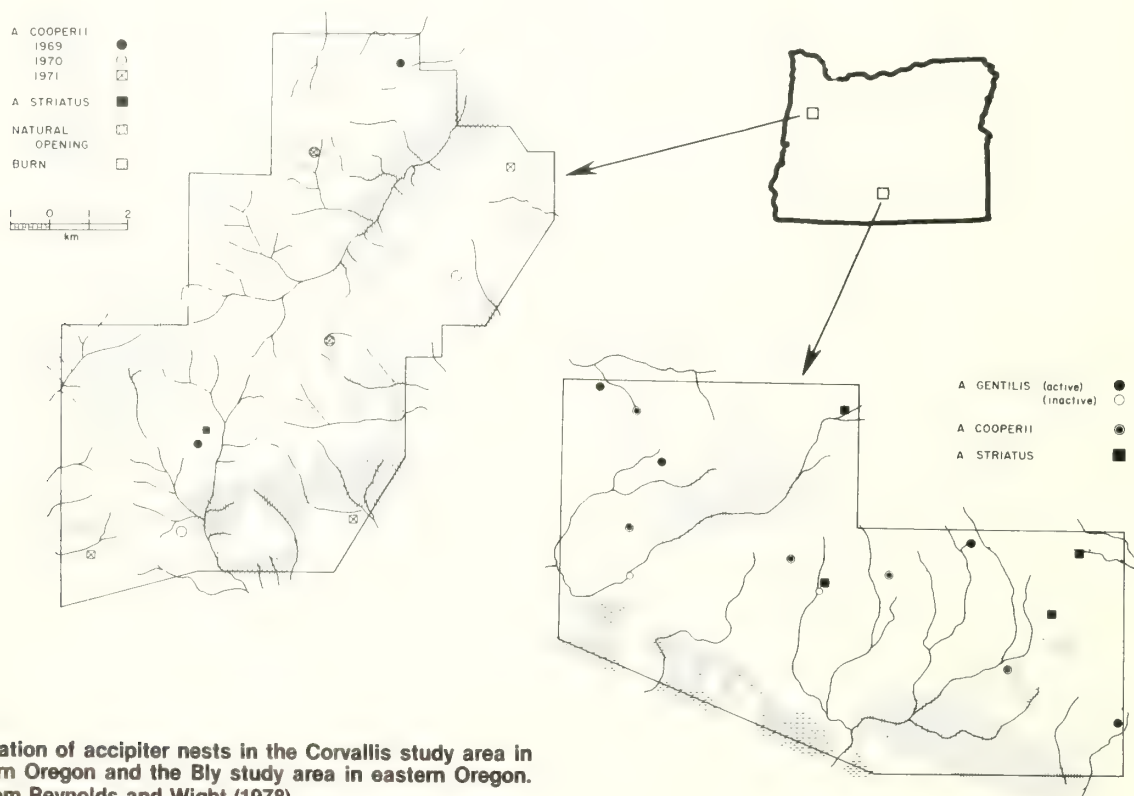


Figure 1. Location of accipiter nests in the Corvallis study area in northwestern Oregon and the Bly study area in eastern Oregon. Adapted from Reynolds and Wight (1978).

closure) and the land form (e.g., slope, aspect) within an area used by a pair and their fledglings during the nesting season (Reynolds et al. 1982). Thus, the boundaries of nest sites were determined by observations of the movements of the adults and fledged young as well as the locations of prey plucking areas and roosts. Nest sites in Oregon measured in this way ranged from approximately 4 ha for sharp-shinned hawks to 6 ha for Cooper's hawks, and from 8 ha to 10 ha for goshawks. Many nest sites had limits that coincided with boundaries between discrete vegetation structures (e.g., a dense patch of second-growth surrounded by mature forest) or tree species (a patch of fir surrounded by pine forests). Other sites had boundaries that coincided with topographic features (e.g., the tops of two parallel ridges on either side of the nest). The boundaries of some sites, however, did not coincide with vegetative or topographic features. These were typically in flat terrain and in large stands with homogeneous vegetative structure.

Bartelt (1974) used a different method to determine the size of the "nesting territory" of goshawks in South Dakota. He approached goshawk nests from various directions and noted the distance at which his approach elicited nest defense from the female. He found that the nesting territories were centered on the nests, and ranged from about 5 ha to 6 ha.

In Oregon, nest sites of the three species had similar physiographic but dissimilar vegetative structures. Most of the nests were on gentle to moderate slopes (0-30%) with northerly exposures (NW-NE) (Reynolds et al. 1982). In addition, most nest sites contained, or were adjacent to, quiet, ephemeral streams or springs. Nest trees typically were located on the lower portions of the slope near the water. In steeper areas, nest sites were frequently on benches or near the bottoms of stream headwalls. However, a few sites of each species were on slopes well above streams. Physiographic features in Oregon were similar to those for nests of the three species in Utah (Hennessy 1978) and for goshawks in both Colorado (Shuster 1980) and South Dakota (Bartelt 1974). In the area of Fairbanks, Alaska, however, the majority of 37 goshawk nests on hillsides had southerly aspects (McGowan 1975).

The most notable vegetative characteristics common to nest sites of the three species in Oregon were high canopy closure and tree density. Both factors, especially when combined with northerly exposures, produced shady, cool conditions below the forest canopy. The principal habitat differences among species were associated with the age of the stands: sharp-shinned hawks nested in from 25- to 50-year-old, even-aged conifer stands; Cooper's hawks in from 30- to 70-year-old, even-aged conifers with somewhat larger and more widely spaced trees; and goshawks in 150+ year-old conifer stands (fig. 2). Mean stand densities in sharp-shinned, Cooper's, and goshawk nest sites were 1,180 per ha, 907 per ha, and 482 per ha, respectively (Reynolds et al. 1982).

The overstocked conditions in sharp-shinned and Cooper's hawk nest sites result in intense competition

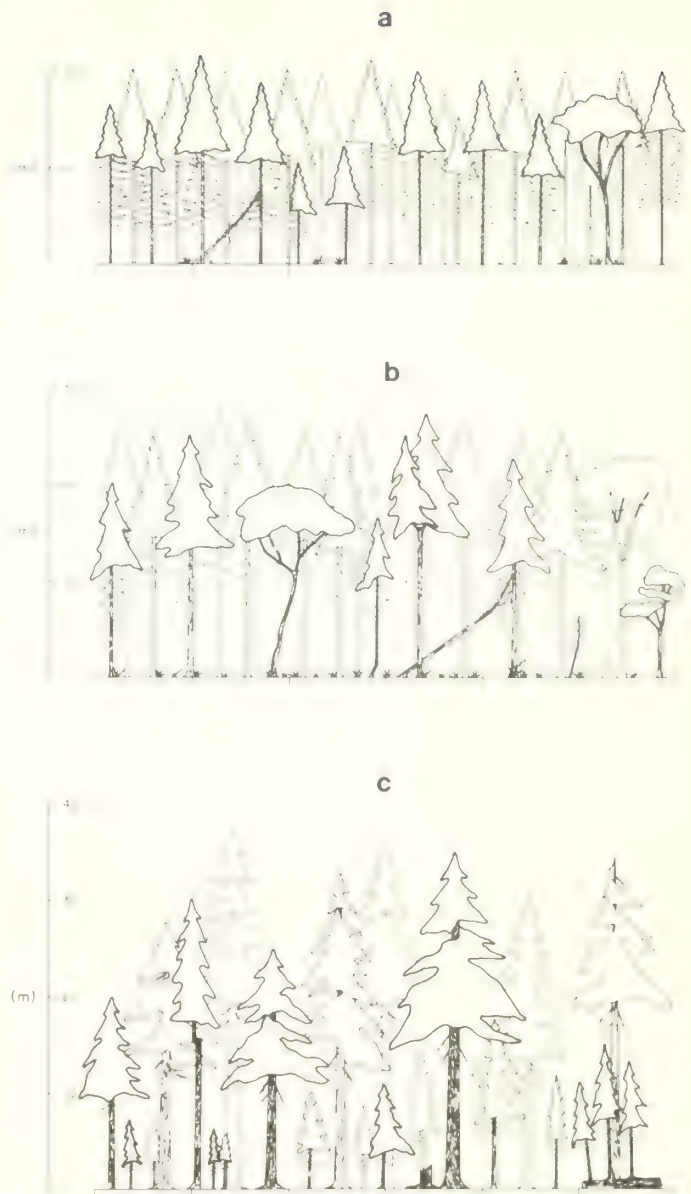


Figure 2. Schematic of the vegetation structure in typical nest sites of accipiter in Oregon. (a) sharp-shinned Hawk, (b) Cooper's Hawk, and (c) goshawk. Taken from Reynolds, et al. (1982).

for light. As a consequence, these stands had shallow canopies and many dead limbs on the boles below the crowns. Sunlight was sufficiently filtered to limit ground vegetation to mosses (*Eurhynchium* spp.) and sword ferns (*Polystichum munitum*). Goshawks require trees with big limbs to support their large nests, and, not surprisingly, tend to place their nests in one of the larger trees on their nest sites (Bartelt 1974, McGowan 1975, Reynolds et al. 1982). Goshawk nests in Oregon were in stands ranging from those with closed, mature canopies with few shade-tolerant understory trees to stands with more open, mature canopies and many understory trees.

During nesting, the activity of a pair (copulation, roosting, prey handling) was concentrated in the area upslope from the nest tree. Roosts, particularly toward the end of the nesting, were marked by accumulations of feces and molted feathers. Prey were plucked on tops of

stumps, logs, and large horizontal limbs below the canopy. Prey plucking areas were marked by accumulations of feathers, fur, and bones. Mean distances of the most frequently used prey plucking area from nest trees for sharp-shinned hawks was 41 m (range 21-52 m), for Cooper's hawks 54 m (range 42-86 m), and for goshawks 45 m (range 27-74 m) (Reynolds et al. 1982).

Nest sites were frequently used for more than 1 year. However, if sharp-shinned hawks and Cooper's hawks reused a nest site, they frequently built new nests, usually within 100 m of the old ones. Goshawks commonly used the same nests for many years, or alternated between two or more nests within a site. Many goshawks and a few Cooper's hawks irregularly used alternate nest sites. Of the three species, the goshawk showed the greatest site fidelity. For example, it was not uncommon for pairs to occupy a single nest site for 5 or more years, and one particular site was still active 10 years after its discovery. Cooper's and sharp-shinned hawks demonstrated much lower site fidelity. Of the Cooper's hawk sites, 27% and 11% were reoccupied the second and third year respectively; 40% of sharp-shinned hawk sites were reoccupied the second year, and none thereafter (Reynolds and Wight 1978). The lesser fidelity of the latter two species may be related to two factors. First, both are small and migratory (Wattell 1973) and may suffer losses to predators and accidents during migration, and, second, due to tree growth and a rapid nest site turnover, pairs of these two species are more often forced to resettle in more suitable stands.

Home Ranges

To investigate the effects of tree harvests on the foraging ecology of accipiters, it is important to know

the size of their foraging areas, as well as the variety of habitats within ranges and the frequency at which each is used.

Home range size of accipiters during breeding has been estimated by: (1) observing marked birds or birds of known identity in areas about nests (Craighead and Craighead 1956); (2) observing adults leaving a nest area above the forest canopy and repeatedly noting the distance and direction traveled (Reynolds 1979); (3) assuming that ranges are circular and nonoverlapping, and using some measure of nest spacing (Newton et al. 1977, Reynolds 1979); (4) plotting the location of capture of marked prey whose remains were found at accipiter nests (Eng and Gullion 1962); and (5) monitoring the movements of adults using radio-telemetry (Marquiss and Newton 1981). Reynolds (1979) compared observations of direction and distance traveled by males leaving nest sites with measures of nest spacing, and found these estimates to be comparable for Cooper's and goshawks but not for sharp-shinned hawks (populations of this species were apparently not at the saturation level). Marquiss and Newton (1981) found that the theoretical mean range size based on nest spacing in sparrowhawks (*A. nisus*) determined by Newton et al. (1977) closely agreed with range size of radio-tagged males in the pre-egg laying and incubation periods. Marquiss and Newton (1981) also demonstrated that home ranges during breeding were centered around nests, and that ranges were smallest when the adults were attending the nest (pre-laying, incubation, and brooding) and increased as the food needs of the family increased.

Estimates of home range sizes in Oregon (Reynolds 1979) were considerably larger than the ranges reported for the same species in Michigan and Wyoming by Craighead and Craighead (1956) (table 1). These differences not only reflect the different techniques used,

Table 1.—Estimates of home range size among species of North American and European accipiter.

Species	Hectares	Explanation	Source
Sharp-skinned hawk (<i>A. striatus</i>)	204	plots of sight records	Craighead and Craighead 1956
	460	1.21 km radius of movement	Reynolds 1979
Cooper's hawk (<i>A. cooperii</i>)	173	plots of sight records	Craighead and Craighead 1956
	1830	2.41 km radius of movement	($\bar{x}$ for Wyoming and Michigan) Meng 1951
	1590	2.34 km radius ($\bar{x}/2$ distance between nests)	Reynolds 1979 (overall mean)
Goshawk (<i>A. g. atricapillus</i>)	212	plots of sight records	Craighead and Craighead 1956
	1979	2.51 km radius of foraging	Eng and Gullion 1962 (Fig. 3)
	2463	2.80 km radius ($\bar{x}/2$ distance between nests)	Reynolds 1979
Sparrowhawk (<i>A. nisus</i>)	1143	35 pairs/400 km ²	Kramer 1955
	1056	18 pairs/190 km ²	Kramer 1955
	1130	21.5 pairs/243 km ²	Tinbergen 1946
	480	9 pairs/43.5 km ²	Tinbergen 1946
	560	1 pair/560 ha	Tinbergen 1946
	305	telemetry, late nestling period	Marquiss and Newton 1981
Goshawk (<i>A. g. gentilis</i>)	2500	16 pairs/400 km ²	Kramer 1955
	3200	14 pairs/450 km ²	van Beusekom 1972
	3000	1 pair over many years	Brüll 1964

but also may reflect an actual geographic variation in range size. Meng (1951) reported that Cooper's hawks in New York foraged up to 2.4 km from the nest, a distance comparable to the observed movement of this species in Oregon. Eng and Gullion (1962) plotted the locations of known capture sites (drumming territories) of marked ruffed grouse (*Bonasa umbellus*) killed by a pair of goshawks and delivered to their nest. The goshawks' range was approximately circular and, although the hawks foraged primarily in an area of 1250 ha, they foraged up to 2.5 km and possibly beyond.

To further evaluate the estimates of range sizes of North American accipiter, they were compared to range size estimates of two European accipiter (table 1) and the relationship between accipiter body weight and range size was examined (fig. 3). The European sparrowhawk (*A. nisus*) is between the sharp-shinned and Cooper's hawks in both weight and home range size, and the European goshawk is similar to the American subspecies in weight and in home range size. Increased

range size with increased body weight not only reflects the increased food demands of the larger hawks, but also the decreased density of their larger prey (Reynolds 1979).

In Oregon, the proportional use of habitat types for foraging was not determined. Observations of foraging hawks indicated, however, that a variety of habitats, from openings to dense forests, were utilized. Because accipiters are more easily seen in openings than in dense forest, it is easy to conclude that these hawks prefer edges or openings (e.g., see Wattel 1973). Marquiss and Newton (1981) found that the sparrowhawks in Britain used woodland more often than expected based on the proportion of woodland in their ranges, and Kenward (1982) found that goshawks in England spent 50% of the daylight hours in woodlands, although only 12% of their ranges were wooded.

Identification of habitat use by North American accipiter will require radio-telemetric monitoring. Hawks should be monitored in both winter and summer, and in

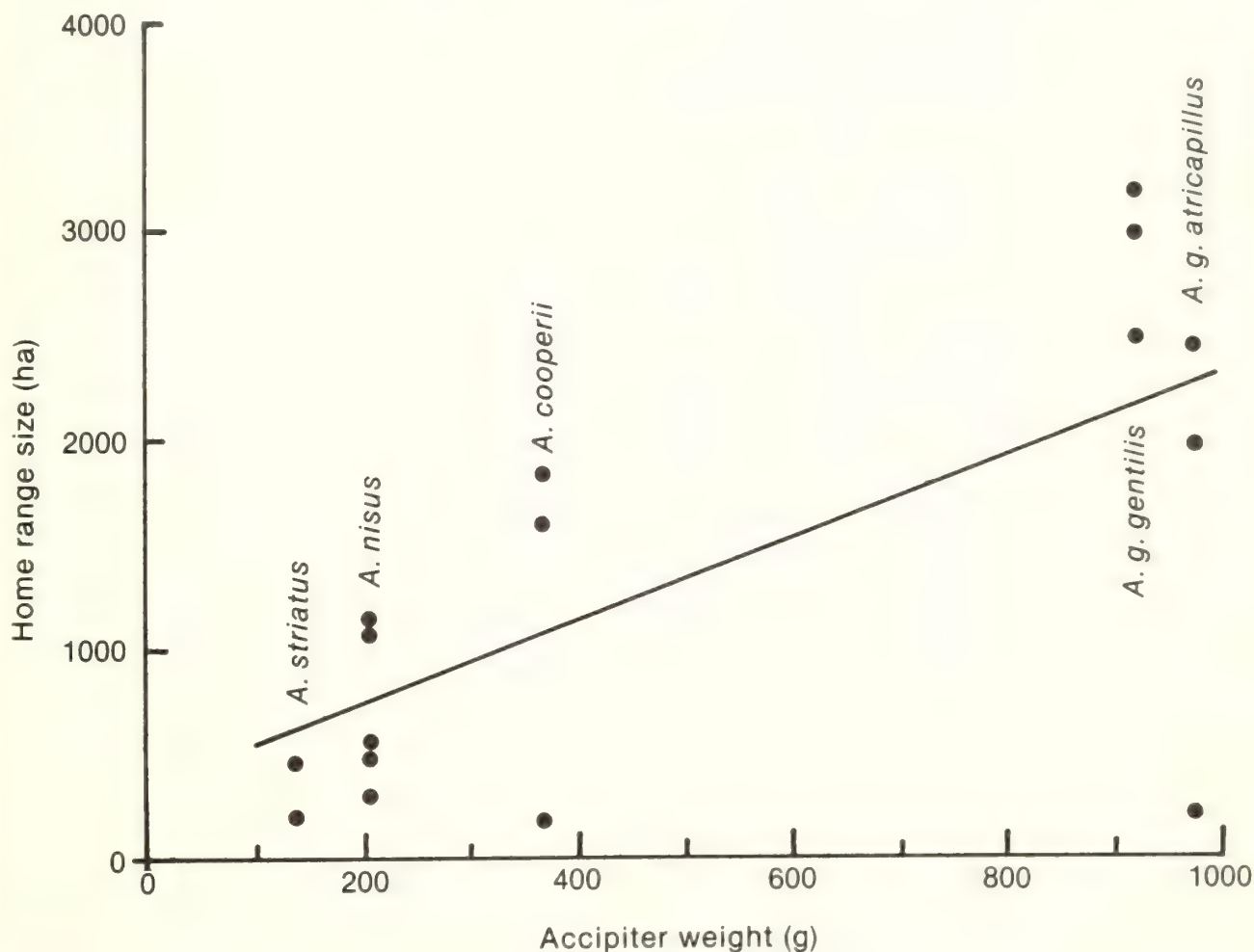


Figure 3. Relationship of estimated home range size to accipiter body weight. Weights are from Storer (1966) and Opdam (1975). Line fitted by least squares.

conjunction with measures of successional stage and age of habitat, vegetation structure, patch size, position in patch, and the spatial relationship of patches with respect to nests (summer) or roosts (winter).

Nest Site Management

To understand the habitat affinities of a species, it is necessary to know whether the species randomly settles into a habitat, or makes an active choice of a habitat. Reynolds et al. (1982) examined nest sites of accipiters by comparing the within- to among-species variation of the habitat variables within nest sites. The analysis showed a significantly greater variation among species, demonstrating that the association of these species with their habitat is at least not random. Reynolds et al. (1982) suggested that the use of dense stands by accipiters was adaptive in that vegetation protected the adults and fledged young from predators and provided shaded, relatively mild environments. If this is true, then accipiters probably choose nest sites on the basis of the stand's overall appearance (e.g., density, height, and presence of water), and, after settling into the stand, select a nest tree. The contention is that the entire nest stand—not just the immediate nest area—is important in accipiter nesting. Choice of a nest tree is secondary; if a pair settles into an acceptable stand, many suitable trees will be available.

If an accipiter nest is found in an area to be harvested, the entire nesting stand should be maintained. Protected areas about accipiter nests should include portions of the stand upslope from the nest containing the plucking and roost sites, the nest, and some portion of the stream (if one is present). The shape of uncut areas will be determined partly by the topography; they should be round or oblong in flat areas, and broad-based triangular or sectorial in steep terrain with the bisecting radius beginning below the nest and running up slope through the nest tree. Nest sites should not be isolated by silvicultural treatments (clearcutting, commercial thinning).

Accipiter nest sites in Oregon represent specific stages in forest stand succession. As a stand matures its structure changes. Thus, a stand is suitable for nesting for a limited time. Change is particularly rapid in sharp-shinned hawk and Cooper's hawk nest sites, because these stands are under intense competition for light—conditions resulting in rapid height growth and, through attrition, stem density reductions. Because of age-related changes, sharp-shinned hawk nesting habitat may become suitable habitat for Cooper's hawks and eventually for goshawks. To maintain nesting populations of accipiters, prospective nest sites with appropriate projected vegetative structure and physiography must be identified before they are precommercially or commercially thinned. Thinning prospective stands will result in reduced tree densities and deeper crowns, and may ultimately reduce their desirability as nest sites.

To maintain accipiter populations, nest sites must be dispersed throughout a management area. Assuming that 1.2 km represents the radius of the home range of a

pair of sharp-shinned hawks, there would be approximately 20 pairs of sharp-shinned hawks per township (9,324 ha, 36 mi²), if the habitat was suitable and if filled to capacity. Providing two potentially active (1 active, 1 alternate site) and two prospective replacement sites for each pair would require a total of 80 sites per township. The distance between the centers or core areas (areas containing the active, alternate, and prospective replacement sites) of the home ranges should approximate the mean distance between nests of neighboring pairs. The potentially active sites and their replacements should be located no farther than 0.5 km apart.

Cooper's hawk pairs should also be provided two potentially active sites and two replacement sites. A mean distance of 4.7 km between nests of Cooper's hawks results in a density of 5 pairs per township. To maintain this density, 10 potentially active and 10 replacement sites should be provided. The active and replacement sites should be dispersed within the core areas in a manner as for sharp-shinned hawks. Sharp-shinned hawk sites that, because of age, are no longer suitable for this species, but lie within a Cooper's hawk core area, should be maintained as replacement sites for Cooper's hawks.

Goshawk pairs also should be provided two potentially active and two replacement nest sites. Because goshawks nest in mature or old-growth stands whose structure is changing relatively slowly, nest sites may be used for many years. However, considering the age of these stands, it is especially important to identify the replacement sites early. Because goshawks require closed or nearly closed canopies of mature trees, tree harvests within replacement stands are not recommended.

A mean distance of 5.6 km between goshawk nests results in an approximate density of four goshawk pairs per township. To maintain this density, eight potentially active sites and eight replacement sites should be provided. The active site and its replacement in each core area should be no farther than 0.5 km apart and no closer than 0.2 km. The distance between an active and alternate site should not exceed 1.0 km.

Cooper's hawk nest sites may be maintained beyond the suitable age for this species to serve as replacement sites for goshawks. However, if the intention is to provide goshawk nest sites by maintaining old sharp-shinned hawk and Cooper's hawk sites, the size of the original leave areas should meet the minimum required by the final target species.

It should be noted that the distance between pairs of hawks and their density is not a one to one relationship; that is, the density varies in proportion to the square of the distance between nests. For example, to manage for one-half of the density in the Oregon study areas, the distance between nests of Cooper's hawks will increase from 4.7 km to 6.7 km, and for goshawks from 5.6 km to 7.9 km. A doubling of the distance between nests may result in a 75% reduction in pairs. In cases where it is not feasible to provide the recommended number of sites, a preferred option is to forego providing alternate nest sites and their prospective replacements rather than opt for a more certain reduction in density by increasing the distance among pairs.

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Availability of nesting sites can limit accipiter populations. Because accipiters nest in dense forest stands, any alteration that opens these stands is likely to lessen their desirability as nest sites. Tree growth and the associated changes in the vegetative structure of aging nest sites limit the number of years sites will be suitable. Therefore, prospective replacement sites should be selected within the core areas of home ranges before precommercial and commercial harvesting begins.

Keywords: *Accipiter striatus*, *Accipiter cooperii*, *Accipiter gentilis*, wildlife habitat

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Mountains



Southwest



Great
Plains

U.S. Department of Agriculture
Forest Service

Rocky Mountain Forest and Range Experiment Station

The Rocky Mountain Station is one of eight regional experiment stations, plus the Forest Products Laboratory and the Washington Office Staff, that make up the Forest Service research organization.

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